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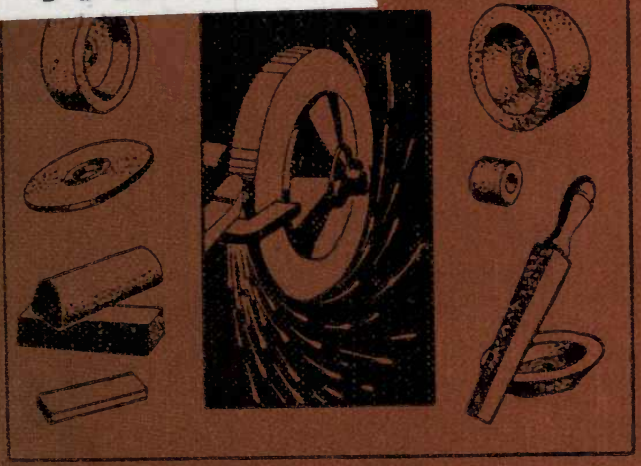

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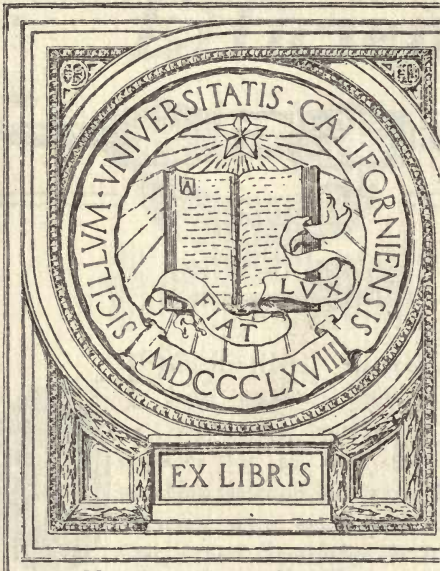


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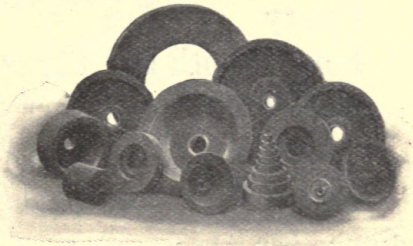

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# THE MANUFACTURE AND USES OF ABRASIVE MATERIALS

A CONCISE TREATMENT OF THE NATURE AND PREPARATION OF RAW MATERIALS, AND THE MANUFACTURE OF ABRASIVE BLOCKS, WHEELS, PAPERS, CLOTHS, POLISHES, ETC.

WITH NOTES ON THE CHARACTERISTICS, SELECTION, AND TESTING OF ABRASIVES, AND MANY EXAMPLES FROM PRACTICE

BY

ALFRED B. SEARLE

*Technical Advisor on Abrasives, etc.*

LONDON
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# PREFACE

THE industrial importance of abrasives is seldom realized, even by those who are concerned in their production. Yet there is scarcely any manufactured article of commerce which does not come in contact with some form of abrasive during one or more stages of manufacture. Such staple articles of food as wheat and oats are ground to flour or meal by means of abrasive stones or crushing rolls, many metallic articles are now "ground to size" instead of being cut or turned as was formerly the case, their rough portions are made smooth or a cutting edge is produced on them by the application of a suitable abrasive "stone," and a fine polish may be imparted to glass, metal, wood, leather, ivory and numerous other materials by means of abrasive powders.

In the engineering industries in particular, recent years have seen the development of much that is entirely new and have also witnessed great extensions in the previous practice of grinding. Much of this development is a direct result of the vast growth of motor work, which offers for solution many problems peculiarly its own, but a large proportion has arisen in consequence of new views relating to the economies of grinding in the wider field of general machine shop practice.

It is hoped that the present volume will prove of value to many who are called upon to deal with



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grinding problems without any very extended or specialized experience in the art. No one can become an expert grinder by reading a book or articles in the technical press, but if the underlying principles of grinding are carefully considered they will frequently assist in solving many of the problems associated with abrasives and with grinding. In solving the more difficult problems, the assistance of a grinding specialist or other expert should be sought and welcomed, as it is easy to incur serious losses through " experimenting " without sufficient knowledge.

ALFRED B. SEARLE.

SHEFFIELD.

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# THE MANUFACTURE AND USES OF ABRASIVE MATERIALS

## CHAPTER I

### ABRASIVE MATERIALS AND THEIR USES

An abrasive may be defined as a material or article employed for removing undesirable projections from other articles and, eventually, for imparting a smooth or even a polished surface to the latter. The action is of an erosive nature, the abrasive material gradually "wearing away" or "grinding off" the material to which it is applied. When the abrasive is in the form of relatively large, sharp pieces the material is removed rapidly by a cutting action, but for polishing—when much smaller particles are used—the object is not to remove the material rapidly but to take such extremely shallow cuts that the material shows no signs of scratches. When abrasives are used in the form of hones, oilstones and whetstones, consisting of very small particles, their action is necessarily slow. Coarser particles would remove too much metal at a time and would prevent a sufficiently sharp cutting edge being produced.

Abrasive wheels are also employed as cutting agents when their employment is cheaper or more

convenient than the use of customary cutting tools.

**Nature of Abrasive Action.** The extent to which one material will wear away or cut away another depends on the hardness of the abrasive, the sharpness of its cutting edges, the pressure at which it is applied, the resistance of the material to be removed and the freedom with which the abraded particles fall away after they have been separated by the action of the abrasive.

The ductile metals yield in a very peculiar manner to abrasives, the grains rolling over one another until each finds its place between some of the remainder. Thus, the raw edges of such a metal as aluminium appear like stiff dough when the metal is prodded with a sharp needle point during microscopical inspection.

Moreover, the cohesion of the various particles of metal to one another is unequal, and during abrasion the looser ones, especially those of a crystalline character, tumble out and leave tiny cavities in their places, thus causing irregularities in their vicinity.

The metallic grains which are larger than those of the abrasive are scored and grooved by the frictional contact, cut up into smaller dimensions, and may become more closely welded together.

The fracturing of the grains of the abrasive during use is of more importance than is generally supposed. Corundum, carborundum, and similar substances, being very hard, do not readily split; but when they do so, they form sharp cutting edges and enable the abrasion to be continued until the

binding particles are reached. The bond must be of such a nature that it breaks off exposing fresh grains of abrasive. Sand (which is somewhat rounded, with a few points and edges) and glass (which is jagged) leave conchoidal surfaces when their grains break ; but although they are serviceable in some ways, the particles are so liable to crumble completely that they are useless for grinding metals.

When grinding hard substances, the sharp ends of the abrasive particles sometimes get worn instead of broken. In some cases this may be beneficial, but it usually entails a loss of gripping and abrasive power.

In grinding and smoothing metals, the abrasion is at first due to the cutting action of the most projecting points of the grains of the abrasive. As these are removed by the friction, a larger number of less-effective prominences are opposed to the metal. Their value is lowered, because the particles of metal which are rubbed off fall between the fixed grains, and are compacted so tightly together as to render the surface of the abrasive smooth and slippery, or "glazed," unless means are found to remove the incorporated dust.

The heat generated on account of friction is often very considerable, but as its area of distribution is circumscribed, it often passes unnoticed. Naturally, when either water or other lubricant is present it tends to prevent too rapid a rise in temperature, but lubricants may introduce undesirable chemical reactions which prevent their being used in some cases.

In dry grinding, the rise in temperature occasionally melts numerous particles of metal, which do not necessarily become removed, but are pressed more firmly into the surrounding interstices, and thereby produce a smoother surface, which is retained when the substance is thoroughly cooled again. If, however, the fusion goes beyond the useful limit the harder grains between the softer ones fall out and leave the metal jagged in parts. This is especially the case with iron and steel. Ductile metals do not disclose this defect so conspicuously as brittle ones.

**Forms of Abrasives.** Abrasives are chiefly employed in the form of : (i) Blocks and stones. (ii) Powder. (iii) Wheels, discs, cylinders, rings, rolls, plates and cups. (iv) Paper coated with abrasive material, e.g. sand-paper. (v) Cloth coated with abrasive material, e.g. emery cloth. (vi) Abrasive liquids, e.g. various metal and other polishes. (vii) Buffing wheels, made of calico and running at from 4,000 to 6,000 r.p.m. for a wheel of 12 in. diam. Each wheel is composed of a large number of discs of cloth, and when the wheel is in motion the edge of the cloth presses against every part of the surface to be polished, even when this is irregular.

(i) *Abrasive Blocks and Stones.* These are usually applied by a simple rubbing action, the stone being rubbed on the article to be abraded, or the latter (in the case of tools requiring to be sharpened) being rubbed to and fro on the abrasive block. Such blocks and stones may be made by cutting or grinding natural stones to the desired shape, or

they may be produced by compressing abrasive powders into blocks as described in Chapter IV.

The chief uses of abrasive blocks are for smoothing and polishing stones and metals, or (in the form of hones, etc.) for sharpening edge tools.

*Combination Stones* which are coarse on one side and fine on the other are made by filling the lower part of the mould with the coarse abrasive mixture, and then completing the filling with the finer mixture. The same bond is used for both materials and it is necessary to proportion the materials very carefully or the two sides of the stone will shrink differently and cause it to crack.

Two stones of different grit and grade are sometimes cemented together.

The stones are usually "finished" by grinding their faces on a revolving bed using carborundum and water as an abrasive.

(ii) *Abrasive Powders* are prepared by crushing the various materials to particles of suitable size. The resulting powder is usually rubbed on the article to be polished, the requisite pressure being applied by means of a rubber made of iron, wood or cloth, as may be most suitable. Water or other liquid may also be used to facilitate the grinding action of the abrasive and to prevent overheating of the article to be polished.

The chief uses of abrasive powders are as smoothing and polishing agents for glass, wood, ivory, leather, various metals, etc.

(iii) *Abrasive Wheels, Discs, Cylinders, etc.* These are usually rotated at a considerable speed so as to produce the same effect as the application of a

great pressure without the disadvantages of the latter.

The earliest form of abrasive wheels—which was extensively used in India long before such wheels were known in Europe—consists of a disc of wood, dressed on the edge with powdered garnets in a matrix of shellac, and mounted on a wooden arbor having an iron peg at each end resting in uprights. It is a near relative of the Indian dead-centre lathe that is driven in just the same way, and both are carried about the country by wandering workmen. Impure garnets unfit for cutting are to be had for the gathering, so the whole machine, including the bit of old leather rein used for driving, is of native origin and manufacture. It is probable, however, that grindstones, made by roughly cutting a sandstone slab into a circular shape and mounting it on a spindle, were in use at an even more remote period. Artificially made wheels have many advantages over those cut from natural stones on account of their greater homogeneity, the much greater variety of abrasive materials which can be used, and the ease with which such wheels may be adapted to suit a great variety of requirements on the part of the users.

For some polishing purposes the wheels are made of canvas, leather, etc., to which the abrasive is fastened by means of glue or cement. Abrasive wheels, discs, caps, rings and cylinders are used so extensively in shaping parts of machinery that to meet modern requirements they must be made with the utmost accuracy and precision, strict attention being paid to many minute details, such

as the size and shape of the constituent particles, the nature and proportion of the binding agent, and the speed at which the wheels are driven.

The action of a modern grinding wheel, disc or cylinder, when at work, resembles that of a steel milling cutter or a circular saw. On the face of

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FIG. 1.—MICROPHOTOGRAPH.

Showing the correct form of chips produced by the cutting action of an abrasive wheel which is suitable for its work.

such a wheel or cylinder the innumerable particles of abrasive material present an even larger number of minute edges which act as tiny cutting teeth, and although these are neither so large nor so strong as the teeth of a cutter or saw, they work at a much greater speed and are consequently far more economical. The chips of abraded material should also resemble those produced by a milling cutter (*see* Fig. 1); when this is not the case (*see*

Fig. 2), an unsuitable wheel has probably been used or a suitable wheel may have been employed in an improper manner.

The uses of grinding wheels and abrasive discs, cylinders, etc., are now so numerous that it is hardly possible to specify all of them. Wherever a material requires to be made accurately to shape, or to be smoothed, some form

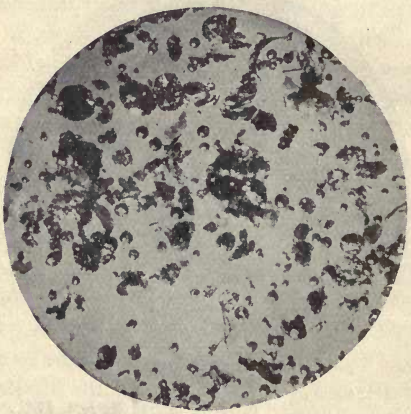

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FIG. 2.—MICROPHOTOGRAPH.

Showing the form of material removed by an abrasive wheel which is unsuitable for its work. Many of the particles have been melted by excessive frictional heat.

of abrasive wheel or cylinder may usually be employed with advantage.

In the manufacture of ball and roller bearings, phonographs, typewriters, adding machines, watches, clocks, registering apparatus, motor cars, tractors, engines of all kinds, agricultural implements and machinery, large numbers of abrasive wheels are employed. The chilled rolls used for crushing, "ironing," etc., are now ground instead of being turned, and when worn they are "trued" by grinding. In the textile industry, grinding wheels are used for sharpening cards; in engineering works they

are used for snagging castings, and in maintaining tools, cutters, and dies. In the leather and shoe industry, grinding wheels are used for buffing hides and for sharpening leather-cutting and shaving knives.

Steel works use grinding wheels for cutting billets of high-speed steel preparatory to rolling into bars. Foundries use abrasive wheels for snagging and for cleaning castings of steel, iron, brass, bronze, and aluminium. On the railways and in allied industries abrasive cylinders are used for grinding locomotive piston-rods and valves, guide-bars, steel car-wheel treads and flanges, wheels, and for surfacing manganese-steel frogs and switches.

The optical industry uses abrasive wheels for grinding lenses, and the cut-glass industry employs grinding wheels to a very large extent for cutting intricate designs on glass ware. In the marble industry, thin abrasive wheels are used for sawing marble into slabs, and thick wheels for surfacing or shaping the marble in various ways.

The final polish on marble slabs used in interior building operations is obtained by means of abrasive blocks composed of very fine grit, silicon-carbide or alundum abrasive, followed by putty powder.

The very thin wheels (some are only $\frac{1}{50}$ in. thick) used by watchmakers, dentists, etc., are made by passing the mixture of abrasive and a rubber binding agent between a pair of smooth, steam-heated rolls, and cutting out the resultant "ribbon" with circular cutters similar to those used by pastry cooks. The discs are then subjected to high pressure and baked as described in Chapter IV.

In the manufacture of bath-tubs, lavatory basins, and other sanitary ware, porcelain, pottery and enamelled iron ware, abrasive wheels are extensively used for removing irregularities on the surface, or for enabling the pieces to be fitted more accurately to each other. In the manufacture of buttons, electrical appliances, articles of rubber, bone, etc., abrasive wheels are now used to a very large extent, and enable much greater outputs to be produced.

(iv) *Abrasive Papers* consist of sheets or rolls of stout paper, one surface of which is covered with a mixture of abrasive powder and a suitable adhesive. The size of the abrasive particles should be selected according to the purpose for which the

abrasive paper is employed, the coarsest particles being used for cleaning purposes, and the smallest particles being preferable for polishing.

The chief uses of abrasive papers are for smoothing and polishing flat surfaces.

(v) *Abrasive Cloths* closely resemble abrasive papers, but the cloth on which the abrasive paper is mounted forms a more flexible support which, for some purposes, is more convenient.

Abrasive cloths are used for the same purposes for which papers are used, and they may also be employed for curved or irregular surfaces which would rapidly destroy abrasive papers.

(vi) *Abrasive Liquids* consist essentially of a solid abrasive material which is suspended in a liquid so as to produce a convenient polishing agent. The function of the liquid is to act as a vehicle for the abrasive powder, enabling it to be applied in small amounts at a time with a maximum of polishing and a minimum of scratching action.

Abrasive liquids are extensively used for polishing metals, but are not so suitable for wood, leather, and other organic materials, on which a polish is produced by filling up depressions in the surface by means of wax, gum or other suitable material, whereas an abrasive liquid produces a polish by grinding away all projections and reducing the whole of the surface to a uniform level.

**Abrasive Materials.** The materials used as abrasives may be divided into two groups: (*a*) natural abrasives; (*b*) artificial abrasives.

(*a*) *Natural Abrasives.* The most important natural abrasives are—

(i) *Stones* of various kinds, including sandstone, rottenstone, pumice, chert, emery, and corundum.

(ii) *Coarse particles*, including diamonds, garnets, and quartz (sand).

(iii) *Powders*, including infusorial earth (kieselguhr), Tripoli powder, diamond dust, and powders produced by crushing pumice, emery, corundum, and other materials, as described in Chapter III.

The natural abrasives which occur as massive minerals are merely cut to the desired shape, but others require to be cleaned and crushed, and may then be mixed with a suitable bond and moulded or compressed into blocks, wheels, or cylinders, of the desired shape ; or the crushed particles may be fastened to cloth, paper, or other suitable support by means of an adhesive.

(*b*) *Artificial Abrasives.* The most important artificial abrasives are—

(i) *Steel Turnings or Filings. Crushed steel* is chiefly used in the United States. It is made at Pittsburg and is there sold as "diamond steel emery." It is used only in the powdered form and is noted for its great hardness, cutting power, and toughness. *Angular grit* is a similar product, made from chilled iron, and is superior to sand for sand-blasting as it abrades quickly without being reduced to powder so rapidly as sand.

(ii) *Aluminous Abrasives.* Artificially prepared corundum and other aluminous abrasives are known by a variety of names, such as alundum, aloxite, borolon, adamite, carbo-corundum, corundite, etc. They are prepared by fusing bauxite or other available forms of alumina in an electric furnace, as described in Chapter III. The best of these aluminous abrasives consist almost wholly of crystals of corundum which resemble the natural mineral (p. 21) in every respect, but are usually purer and harder. When properly prepared, artificial corundum shows signs of fusion at about 2,050° C.

(iii) *Silicide or Carbide Abrasives.* This group includes silicon carbide (or carbon silicide) and similar substances prepared by fusing sand and carbon in an electric furnace. Silicide or carbide abrasives are also known by several trade names—including carborundum, carbalon, crystolon, carbosilite, diamantin, dynamidon, and dialunite—and are made by heating coke, sand, sawdust, and a little salt in an electric furnace until the carbon in the coke

and sawdust combine with the silicon in the sand and produce a new compound which may be termed silicon carbide or carbon silicide, as it is composed of 70 per cent of silicon and 30 per cent of carbon. The compound is represented by the formula SiC. These abrasives are harder than artificially prepared corundum, and much harder than emery, but they are not so tough. For some purposes, their brittleness is an advantage, as the grains break before the edges are dulled and so expose fresh cutting edges and promote rapid work.

*Carborundum* was first prepared by E. G. Acheson, in 1891, and was the first artificial abrasive material to be manufactured on a large scale. It is one of the hardest of abrasives and possesses great durability. It is made up of small, sharp crystals, which are just brittle enough to break slightly when in use. The sharp edges of the crystals cut clean and fast; while the brittleness, by constantly presenting fresh cutting edges, prevents glazing. The combination of these qualities—durability, rapidity, and uniform efficiency—makes carborundum one of the best of abrasives.

Carborundum is insoluble in all ordinary acids, but is slowly attacked by hydrofluoric acid. It is insoluble in water and this is an invaluable property in any grinding material, as the use of water expedites the work and catches almost all of the dust.

(iv) *Rouge* and *crocus martis* are highly hydrated oxides of iron. They are made by heating ferrous sulphate in crucibles until all the sulphur has been volatilized. Their precise composition is not known nor is the cause of their difference in colour, rouge being red and crocus martis purple. The precipitated hydrates of iron do not give good results, as their consistency is gelatinous; they do not form the spongy articles which have the desired abrasive nature. Black oxide of iron is the principal ingredient of the trade article *Glassite*.

(v) *Putty powder*, i.e. tin oxide, was formerly used largely as a polishing medium, although not superior to rouge; it is now prohibited on account of its poisonous nature.

(vi) *Manganese dioxide* is an excellent polishing medium, but not frequently used, owing to its blackness; it is very difficult to remove it from the pores of the skin.

(vii) *Whiting* and *slaked lime* are both extensively used as abrasive powders, being chiefly employed in polishes.

(viii) *Bath bricks* are made of river silt which is moulded, dried and burned at a dull red heat. These bricks and the powder obtained by crushing them are used extensively for cleaning and rough polishing.

It should be noted that the above-mentioned artificial abrasives are prepared from various materials which are not necessarily of an abrasive character. Thus, artificial corundum is made by fusing bauxite, which is a very soft mineral, and carborundum is made by heating sand, coke, and sawdust in an electric furnace.

**Proprietary Names.** The trade names of the principal artificial abrasives are as follows :—

*Adamite* is an Austrian product, containing only about 80 per cent of alumina. It is very dark blue—almost black—in colour and remarkably tough considering the proportion of impurities present.

*Aloxite* is artificial corundum made by the Carborundum Company in the south of France, and at their Niagara works. It has a purplish-blue colour and is highly crystalline.

*Alundum* is the registered name for the artificial corundum made by the Norton Company, Chippawa, Canada.

*Borocarbone* is made in France and closely resembles the other aluminous abrasives.

*Carborundum* is the trade mark of a firm, but it is now applied generally to silicon-carbide, even when that material is produced by other firms.

*Carbosilite* is very similar to carborundum, but less pure. It is made in Germany.

*Corubin* is a crude form of fused alumina picked out of the slag produced in the manufacture of chromium by the Goldschmidt " Thermit " process.

*Crystolon* is the trade name of carborundum, made by the Norton Company, Chippawa, Canada.

*Electrolon* is a carborundum made by the Abrasive Company, Philadelphia.

*Oxyalumina* is an American product made by fusing earths similar to bauxite.

*New names* are constantly being introduced but most of

them relate to one form or another of artificial corundum or of silicon carbide.

## CHAPTER II

### RAW MATERIALS

As explained in the previous chapter, the raw materials used in the manufacture of abrasives may be the abrasives themselves (as is the case with the natural abrasives) or they may be substances of little or no abrasive power, such as bauxite, coke, sawdust, etc.

The most important of these raw materials are : (1) *For natural abrasives*—sandstones, rottenstone, tripoli, kieselguhr, pumice, emery, chert, etc. ; (2) *For artificial abrasives* — sand, bauxite, coke, sawdust or other carbonaceous material.

**Sandstones.** The chief stones used for abrasive purposes are sandstones which occur in large masses in many parts of the world. These stones are composed of grains of sand (i.e. of impure silica, usually in the form of quartz) firmly united with a bond of amorphous silica. The lightness of the colour is a rough guide to the purity of a sandstone but not to its utility as an abrasive material.

Until comparatively recent years, the deposits of *Millstone Grit* in Derbyshire, and especially around Matlock, served to furnish grindstones for all purposes, but similar stones, found in other localities, are also used. The grades vary, even in one quarry, from fine to very coarse and from

very hard to soft. Many sandstones are not suitable as grinding agents as they lack sufficient tensile strength and uniformity.

When suitable, sandstones form a cheap and generally satisfactory abrasive material, but they wear away so much more rapidly, and consequently produce so much more dust than good artificially prepared stones, that the latter prove to be cheaper in the end, though more costly at first.

In selecting a sandstone from which to produce grindstones or abrasive blocks, attention must be paid to the sizes of the particles, their angularity, and to the nature and proportion of the bonding material. The selection requires both care and skill as it is far from easy to distinguish good stones from some of inferior quality merely by their appearance. Lately, harder abrasives have, to some extent though by no means entirely, superseded the natural stones.

For some purposes, sandstones are crushed and the resultant *sand* is used as an abrasive. To be effective, the particles of sand should be angular, not rounded.

**Oilstones.** These are composed of fine-grained sandstones or slates, the particles of which are united by a natural cement composed of silica. They are called oilstones because they work most efficiently when supplied with oil. *Turkey stone*, mined in Asia Minor, is an argillaceous or slatey stone with minute particles of quartz in it, which impart its sharpening power. The *Belgian razor stone* is a natural sandstone containing innumerable tiny garnets, to which its chief value is due.

Artificial oilstones are made of fine-grained carborundum or corundum with a silicate bond.

The stones are immersed in oil prior to use, and require the use of further oil to remove the dust and particles ground from the knife blade, and to serve as an external lubricating agent. The objection is sometimes urged that artificial oilstones must be porous in order to hold the oil, and so have relatively large pores which are gradually filled with dirt and metal. Furthermore, the oil dries up or oxidizes on the surface of the stone and, in time, interferes with sharpening operations. It has also been found that the oil tends to adhere to the surface of surgical instruments which are being sharpened, and so prevents proper sterilization afterwards.

**Hones.** Hones of various shapes are usually cut from sandstones, but many of the more modern ones are made with a shellac bond; for razor hones a silicate or vitrified bond is usually employed. Artificially-made stones and hones are usually more uniform in texture and hardness than the natural stones, and are, consequently, to be preferred.

The action of abrasives when used in the form of hones, oilstones, and whetstones differs from that when used in the form of wheels, as the cutting action in stones is much slower. To produce a keen, sharp edge on the metal, it is necessary for the abrasive particles to be of small size. The stones are used either with water or oil, or, in rare instances, in a dry state.

**Rottenstone.** This is a soft siliceous stone of a

yellowish-grey or brownish colour and of a very fine texture. It consists of the siliceous skeleton left behind after the solution of calcium carbonate from dark-coloured impure limestones.

*Kieselguhr* and *diatomite* are earths composed of the siliceous remains of minute forms of life, and may readily be identified under the microscope.

**Tripoli.** This material is also composed of siliceous skeletons, and is often almost white in colour. It usually contains about 80 per cent silica, a small amount of alumina, and up to 8 per cent of iron. In some cases, however, the material contains much alumina and little silica. The best quality of tripoli is found at Corfu.

**Chert.** Chert—which is known locally as *malmstone*, *hearthstone*, and *firestone*—is a siliceous stone very similar to flint in composition and occurrence. It consists chiefly of the siliceous spiculae of sponges, together with fragments of foraminiferae and other marine shells, and crystalline silica. It occurs in irregular masses in almost all the strata of the Upper and Lower Greensand, and in the Portlandian formation. It also occurs extensively in the Carboniferous Limestone, being quarried at Bakewell in Derbyshire for grindstones. It is also quarried near Holywell and Prestatyn in Wales. It varies in colour from light grey to black, is frequently banded, and has a radiating structure.

**Clay.** The polishing value of highly burned clay, which has afterwards been finely ground and levigated, is seldom properly appreciated, though this material is used in a number of polishing liquids instead of sand or other forms of silica.

Bath bricks, which are made of a muddy deposit from the River Parret at Bridgwater, have long been known as excellent for rough polishing, and a similar material when sufficiently finely ground is used as an ingredient of high-class polishing fluids.

Very fine particles of burned clay have a much greater polishing effect than rouge; and for the final polish, raw clay of sufficient fineness, such as china clay and some of the finer pipe clays, is invaluable, as its particles are so minute that they polish without scratching.

**Alumina** is closely allied to burned clay in its polishing properties. The form of alumina used for this is *red sludge*, which is a by-product of some importance, obtained in large quantities in the manufacture of pure alumina from bauxite or clay. In addition to oxide of iron, it contains small quantities of caustic alkalies or soda, all of which have a cleansing influence. The well-washed red sludge is dried, finely ground, and sifted. Owing to the manner of its production, it consists of very fine particles which, under some conditions, are sufficiently angular to form an excellent polishing agent and of much greater power than rouge.

**Pumice.** This is an igneous rock which has been cooled very rapidly from the molten state. It is generally used in the form of powder, but pumice blocks are also used. Owing to its porous character it has a low specific gravity, and can therefore be separated from some of the impurities present by a process of flotation in water. Pumice requires to be selected with care, as the felspar and other

impurities present are usually harder than the pumice and tend to scratch the articles which the pumice is intended to polish.

**Emery.** Emery is a natural mineral consisting of impure crystalline alumina (*see* corundum, p. 21) mixed with about half its weight of black, magnetic iron oxide. This ingredient has little or no cutting power and so reduces the abrasive power of the mixture, but it is of value as a bond in the manufacture of vitrified wheels.

The chief sources of emery are in the basins of the Sarabat and Mender rivers in Turkey and on the Isle of Naxos in Greece. In the United States, the deposits at Chester (Mass), and Peekskill (N.Y.) are also used. The Grecian material is usually the best.

Emery grains are very dark in colour (owing to the black iron oxide present) and are tough and durable. The chief impurities are tourmaline, magnetite, and mica. The surface of the grains is so rough that they are retained very well by the bond or adhesive. The specific gravity lies between 2·7 and 4·3, according to the proportion of impurities present, and the percentage of alumina varies from as low as 10 to as high as 75 per cent, with an average, for the material used in this country, of about 64 per cent, but the proportion of true corundum (crystalline alumina) present seldom exceeds 50 per cent. Some users of abrasives fail to understand that the difference between emery and corundum is merely one of purity and not of any essential difference in the nature of the material.

The relative abrasive powers of different samples of crushed emery are best judged from the percentage of alumina present, and the appearance of the particles when viewed through a microscope under a magnification of 75 diameters. The microscope readily shows the amount of angularity of the grains, to which their abrasive action is chiefly due, and it also gives some idea of the proportion of iron oxide and other materials of low abrasive power.

If the particles in a sample of crushed emery are rounded or have few sharp angles, the abrasive power will be low, whilst another sample in which all the grains are highly angular, but of very small size, will be useless where coarser particles are required. Owing to the roughness of the particles emery is sometimes preferred to more modern abrasives as it is retained more firmly by the glue or cement used to hold it on to the cloth, etc., on which it is applied to the articles to be polished.

Although the value of emery as an abrasive material was known to the ancient Greeks, its use was very limited prior to 1870, when means were discovered for producing satisfactory artificial grinding stones from crushed emery and a bonding agent. Since then emery has gradually been displaced by artificially prepared materials which contain less impurities, and so have a better abrasive action, are more uniform in action, and can be better adjusted to the requirements of the user.

Notwithstanding the efficiency of many artificial abrasives, natural emery still holds the field for grinding some classes of steel castings and heavy malleable irons.

Emery wheels are relatively low in price and so are popular among users who only employ them intermittently, and therefore are not concerned to use an abrasive of the very highest efficiency at a correspondingly high price.

Owing to the presence of the softer iron oxide, emery leaves a finer finish than abrasives made of nearly pure corundum or silicon carbide. This is important in some precision work, such as gauge grinding.

Artificially-made emery wheels are largely used for grinding wheat and oats and for polishing rice, as they have been found to be superior to many of the wheels of natural stone formerly used for these purposes.

Blocks or bricks made of coarse emery are used for rubbing stone and metals, the finer grades of emery are made into sharpening stones for knives, scythes, etc.

Emery powder is used for finishing bevels on plate glass, lapping hardened steel, polishing gems, metals, edge tools, parts of firearms, etc.

**Corundum.** Corundum occurs as a natural mineral composed almost wholly of crystalline alumina and, though it is seldom quite pure, it ought not to contain less than 96 per cent of alumina. Corundum is brownish-yellow to pale yellow in colour, and the purest crystals are quite transparent and almost colourless. The mineral is worked in Eastern Ontario (Canada), in India, and in small quantities in North Carolina and Georgia, U.S.A., and elsewhere ; but the superiority of artificially prepared corundum and the fact that, for most purposes, carborundum and other silicide abrasives are cheaper and equally effective, have prevented natural corundum from being as widely used as it might otherwise have been.

Corundum occurs in syenite and peridotite rocks : (*a*) as massive blocks which, owing to their hardness, are extremely difficult to break ; (*b*) as smaller masses of crystalline alumina ; and (*c*) as corundum sand. The material is often mixed with felspar, hornblende, mica, garnet, etc., and it is sometimes very difficult to purify it. Corundum, when pure, is wholly abrasive and does not

" rub " or " glaze " like emery and other impure abrasives. The particles of corundum are much lighter in colour than those of emery, the dark colour of the latter being due to the iron oxide present. The crystals of corundum are of the hexagonal system and they are sharper and more angular than those of emery, and, being harder, they remain sharp for a longer time. Corundum crystals possess no definite cleavage, but, in larger masses, there are usually parting planes along which the crystals fracture. Care should be taken in selecting corundum that the parting planes do not run through the small crystals used for abrasive purposes or the particles may break prematurely along these planes and the efficiency of the material will be reduced.

The hardness of corundum for various sources is about 9 on Mohs' scale (p. 76), i.e. that of the sapphire, but the abrasive power of different specimens of corundum varies greatly.

Neither emery nor natural corundum are so uniform in angularity (sharpness) and hardness as the artificially-prepared aluminous abrasives, described on pp. 11 and 31.

Although corundum is a particularly good abrasive where a hard material of great cutting power is required, the carelessness and ignorance of some manufacturers of grinding wheels, blocks, etc., made of corundum has led to unfavourable opinions being formed by some users. This is a matter of great regret, as in most of the cases investigated by the author, the poor results obtained have not been due to the corundum but to the manner in which the wheels and blocks have been made.

The hardness and cutting power of natural corundum depends chiefly on : (*a*) the use of true corundum and not diaspore which has a similar chemical composition

but is a much softer material; (*b*) the absence of notable proportions of impurities, particularly lime compounds; and (*c*) the shape of the crystals, which indicates whether they have been produced under suitable conditions. The variations in the hardness of natural corundum are very great, and range from a relative hardness of 58 (an American specimen) to 94 (a Canadian corundum) and 100 (Indian sapphire, taken as a standard).

**Sand.** Quartz, which is one form of silica, is one of the commonest and most widely distributed minerals, and is the chief constituent of most sands. Its crystals are well defined, have no marked cleavage, but break with a conchoidal fracture. Its hardness number is 7 on Mohs' scale, and its specific gravity is 2·64.

As an abrasive, quartz is chiefly used in the form of a sharp white sand, the individual grains of which are seen to be glass-clean when examined with a powerful lens.

Loose quartz is chiefly used as an abrasive for polishing glass and for sawing stone, but it is also employed in the form of *glass-paper* or *sand-paper* for smoothing wood, leather, etc. In the form of natural sandstone it is used extensively in the manufacture of grindstones, but sand which has been mixed with a bond and made into grindstones is not satisfactory. Fine sand is one of the chief ingredients used in the manufacture of silicon carbide abrasives, as described in Chapter IV.

Only those sands can be used for polishing and abrasive purposes which consist of sharp grains of almost pure silica. Grains with rounded edges possess little or no abrasive power, whilst those containing much impurity soon have their edges

coated with the latter (which is usually of a softer nature than the silica), and so cease to be useful.

Sands used for polishing and fine grinding must also consist of grains of as nearly as possible uniform size, or the surface will be unduly scratched.

Sands for these purposes can best be valued by examining them under the microscope, as by this means the sizes of the grains may be seen, their shape and general nature observed; and if the microscope is provided with the necessary fittings, the various minerals present may be identified and their proportions determined with sufficient accuracy.

**Garnets.** The term "garnet" is applied to a group of minerals, the essential composition of which corresponds to the calcium alumino-silicate $Ca_2Al_2Si_3O_{12}$, though in some garnets the calcium is replaced by iron or magnesium or the alumina by chromium.

Garnets occur very extensively, but usually in quantities too small to be of commercial value. The chief sources at present are Spain ("Spanish mineral" used for garnet cloth), India, and the Adirondack mountains in the United States.

Garnets are softer than either emery or corundum, their hardness being between 6·3 and 7·5 on Mohs' scale. Their specific gravity varies from 3·3 to 4·4.

Garnets are not very suitable for the manufacture of grinding wheels but are highly satisfactory when fastened to cloth or other suitable support

by means of glue or cement, and used for smoothing wood, etc.

**Diamonds.** The diamonds (including carbonado and bort) used as an abrasive material are precisely the same as those regarded as precious gems, except for flaws, discoloration, etc., which do not detract appreciably from the abrasive qualities of the material though they render it useless for ornamental purposes.

The chief diamond mines are in South Africa, but this mineral also occurs in India, Brazil, New South Wales, Borneo, and British Guiana. Most diamonds occur in a blue clay, but carbonado or black Brazilian diamonds occur in gravel.

Diamonds crystallize in the cubic system and when perfect in shape they take the form of a double pyramid or octahedron. The fracture is conchoidal, cleavage occurring along planes parallel to the faces of the crystal. The true diamond is the hardest substance known, and is indicated by the figure 10 on Mohs' scale. Its specific gravity is 3·5. Carbonado has a rather lower specific gravity than other diamonds; it has no true cleavage and breaks with a granular fracture; and its colour ranges from " water clear " through brown to black, yellow diamonds being found in the largest numbers.

In use, the diamonds are mounted on the circumference of a wheel made of copper or cast iron, so that they project like the teeth of a circular saw. Occasionally they are mounted on a metal slide which is moved to and fro by means of a crank or other reciprocating mechanism.

## CONSTITUENTS OF ARTIFICIALLY PREPARED ABRASIVES

The principal ingredients used in the manufacture of artificial abrasives (*see* also Chapter III) are as follows—

*Angular Grit.* *See Crushed Steel*, p. 11.

*Bauxite.* A natural aluminium hydroxide first found in the hills around Les Beaux in South of France—is a soft earth which is light yellow or buff when pure, and deep red when seriously contaminated with iron oxide.

It occurs extensively in Ireland, Australia, France, Germany, Austria-Hungary, Italy, Africa, India, and in the United States. It is also a by-product from some chemical works. Bauxite is almost destitute of abrasive power, and can only be used for this purpose after it has been fused and allowed to cool slowly, whereby crystals of corundum are formed.

*Coke* is used in the manufacture of the silicon carbide abrasives. In itself it is almost destitute of abrasive power.

*Green vitriol*, or ferrous sulphate, is used in the manufacture of rouge and crocus martis.

*Salt* (sodium chloride) is added to the materials used in the manufacture of silicon carbide abrasives in order to convert any iron, etc., present into chlorides which are volatilized at the high temperature attained in the electric furnace. Salt thus acts as a valuable purifying agent.

*Sand* is chiefly used in the manufacture of the silicon carbide abrasives (p. 34).

*Sawdust* is used in the manufacture of silicon carbide abrasives, it being added to the mixture of coke and sand to make the mass porous and thereby permit the escape of the gases generated during the process.

*Silt* from the River Parret, in Somerset, is moulded into small bricks which are dried, burned and sold as Bath bricks. Some people prefer to use the powder formed by grinding broken Bath bricks.

*Various materials* are sometimes used as a source of abrasives for polishing and cleaning purposes. Their composition is unimportant provided they possess the desired physical properties and can be readily freed from objectionable constituents Thus, finely granulated slags

and the waste products of various industries are largely used as abrasives in certain soaps and cleaning agents.

## BINDING MATERIALS

In the manufacture of abrasive blocks, wheels, and cylinders it is often necessary to bind the particles of abrasive material by means of a suitable adhesive. The bonds used are of five types—

(i) Glues or cements such as those used for abrasive paper and cloth.

The glues and cements used as binding agents should be of good quality; if inferior ones are used, the abrasive is liable to break away without working efficiently.

(ii) Elastic bonds, such as celluloid, rubber or vulcanite, asphaltum, tanite or shellac.

As in the case of glues and cements, the bond must be of good quality to prevent the abrasive from breaking away prematurely. Shellac may be improved by melting, skimming, cooling, and then breaking it into lumps. It is next ground to fine powder and is then ready for use.

(iii) Silicate bonds, chiefly water-glass (silicate of soda).

The water-glass used is a thick viscous liquid, the value of which depends on its specific gravity, which is the simplest measure of the sodium silicate present. Rock silicate is similar in composition to water-glass but contains only a small proportion of water. As it must be dissolved in water before use, there is little or no advantage in using it instead of water-glass, and the latter is much cheaper.

(iv) Hydrous cements, such as Portland cement and Sorel cement.

Portland cement is not satisfactory as a binding agent for abrasive materials, and its use has now been abandoned except by a few experimenters.

Sorel cement (made of magnesia and magnesium chloride) and a similar cement made of zinc oxide and phosphoric acid have been used. They enable grinding

wheels and the like to be made very cheaply, but the products are unreliable and for that reason should not be used except under such conditions as are free from all risk to the user.

In such cases, the bond should be made of the best materials, as undue striving after cheapness may have disastrous results.

### (v) Vitrified bonds composed of fusible clays, mixtures of felspar and china clay, or mixtures resembling hard paste porcelain.

Vitrified bonds are seldom made of a single material, though some fusible clays have been used satisfactorily for this purpose. More often, such bonds are composed of a mixture of china clay, felspar, flint, and whiting, with or without the addition of ground glass or enamel. Under normal conditions glass and enamel do not produce good bonds as, when melted, they are too fluid and, when solid, they are too sensitive to sudden changes in temperature.

The simplest vitrified bonding material is a natural clay occurring near Klingenberg, Germany. No precisely similar clay has been found in the British Isles. Where the bond consists wholly of a single clay the latter must melt completely to a slag-like material at or below 1,400° C.

It is often stated in articles on abrasive wheels that refractory clays, such as kaolins or china clays, are used as bonds. This is incorrect, as such clays are too infusible ; they may, however, be mixed with felspar and a very good bond be thereby produced.

Felspar—a complex mineral silicate fusing at 1,300° C. —is sometimes used alone as a vitrified bond, but it lacks viscosity and toughness unless clay is mixed with it.

Hard paste porcelains are made of mixtures of finely ground felspar, flint, and china clay. A typical composition is : clay, 50 parts ; felspar, 25 parts ; and flint, 25 parts. By modifying the proportions of these ingredients, bonds of varying hardness, toughness, and fusibility may be prepared. As the particles of abrasive should be completely covered with the bonding particles, and the proportion of the latter should be as low as possible—as the bond has very little abrasive power—it is essential that the binding material should be finely ground. The various ingredients should be ground together until the

mixture will pass completely through a sieve having 100 holes per linear inch.

The production of a wholly satisfactory vitrified bond is a matter requiring great care and skill. As abrasive tools are required for so many different purposes, the manufacturers have to produce them in many grades, each of which has a different proportion of bond or a different bonding agent.

The nature and proportion of bonding material must be so chosen that the abrasive article has the desired hardness, and that, in use, it maintains its abrasive character without "glazing" on account of an excess of bond, or wearing away too rapidly and irregularly because an insufficient amount of bond, or a bond of unsuitable nature, has been used.

The precise proportions depend so much on many minute details connected with the manufacture that recipes would be out of place in this primer. Roughly, about 10 per cent of bond is used, but, as already stated, the actual proportion varies within somewhat wide limits. It may be as low as 5 per cent and as high as 25 per cent.

A good vitrified bond should not melt below Seger cone 8 (1,250° C.); when molten it should be a thick viscid fluid which solidifies on cooling to a tough glassy mass of great strength, not very brittle and not readily affected by sudden changes in temperature. If the bonds melt at too low a temperature the articles in which it is used will be blistered and irregular in composition. If the molten bond is too fluid the articles will warp unduly during the firing.

Many other binding materials have been tried, but they have been found to be unsuitable as the conditions under which grinding wheels, etc., are used are very severe and require a bond of exceptional strength.

Each of the five types of bond, mentioned above, has its special advantages for particular purposes but the vitrified bonds are regarded as the most scientific and efficient, as in them the binding material employed is in itself a fairly good abrasive, whereas, with other bonds, substances are employed

which are decidedly injurious to the wheel, in some cases causing a gumming or glazing, and in others a softening when exposed to moisture.

Among the advantages claimed for wheels with vitrified bond are ability to cut faster and more freely, to do more work, and to hold their shape better than wheels with glutinous cement or bond. The vitrified bond is of the nature of a hard porcelain, and the wheel has relatively less weight than any other kind of wheel, and is less liable to burst. A wheel with a vitrified bond can be hard or soft, and of any degree of fineness or coarseness desired to adapt it to every kind of work ; it can be run equally well wet or dry, and successfully resists the action of either oils or acids.

## CHAPTER III

### PREPARATION OF ABRASIVE MATERIALS

THE preparation of abrasive materials consists essentially of either four or five stages according as the materials employed occur in Nature or have to be made artificially. In the latter case, the five stages are—

(1) Production of the abrasive material from other substances.

(2) Crushing the abrasive.

(3) Cleaning the abrasive to free it from adherent impurities.

(4) Grinding the abrasive.

(5) Grading or sorting the abrasive material into particles of suitable sizes.

In the case of emery and other "natural" abrasives the first of these stages is omitted.

## PRODUCTION OF ARTIFICIAL ABRASIVES

As the present volume is a primer, the full details of the various methods of producing various abrasive materials are not described in the following pages, but sufficient information is presented to give the reader an intelligent grasp of the subject. For the same reason, only a limited number of abrasive materials has been selected, and the production of such materials as whiting, lime, and other substances which are common commodities or by-products from other industries is not described.

As previously stated (pp. 10, 14, 26), artificial abrasives are chiefly of two kinds: (*a*) those which consist chiefly of fused alumina, typified by alundum; and (*b*) those which consist chiefly of silicon carbide and are popularly known as carborundum, though this word is strictly a trade-mark belonging to one particular firm.

**Preparation of Re-crystallized Alumina.** Artificially-fused re-crystallized alumina or corundum is made by fusing calcined* bauxite (p. 26) or emery† (p. 19) in an electric furnace of the arc type using carbon electrodes.

* Calcination at a red heat decomposes the hydrous alumina and drives off the water thus liberated at a much lower cost than if the raw bauxite were placed directly in the electric furnace.

† When emery is used, charcoal or coke must be mixed with it so as to reduce any iron compounds to the metallic state.

The process is simple, yet by no means easy to work profitably, on account of the very powerful electric currents employed and the exceedingly high temperatures to be attained (far above that required in steel manufacture).

The furnace consists of a square or circular chamber which may be built of firebricks, or made of sheet iron, lined with graphite or coke dust, which is kept cool by water flowing over it. In the latter case, the chamber must be large and the part of the charge of bauxite nearest the walls acts as a container. In the centre of the chamber are two carbon electrodes or rods which carry the current; they are mounted on rack-work in such a manner that the lower end of one rod can be made to touch that of the other or can be kept at any desired distance from it.

At the bottom of the chamber is placed several pounds of iron or steel turnings and the two lower ends of the electrodes are brought into contact with these. If the current is then switched on an arc is formed and the iron is rapidly melted. Before complete fusion occurs, bauxite is shovelled into the furnace in small quantities at a time and at such a rate as to make the best use of the heat developed by the electric arc. When the temperature of the bauxite is about 2,200° C. it melts and, owing to the highly reducing action of the arc flame, any iron compounds present are reduced to the metallic state. As fusion proceeds, the material becomes so intensely hot that most of the silica is volatilized and so escapes. Finally the metallic iron settles to the bottom of the

furnace, the molten alumina occupies a central position with a light slag, due to various impurities, above it, and unfused bauxite all around. From time to time, the molten iron may be run off, but with an almost pure bauxite there will not be sufficient iron to permit this. When no more alumina can be fused in the furnace, the current is switched off and the furnace is allowed to cool. The current is usually alternating and the consumption may be 300 A at 110 V, but for the larger furnaces 6,000 A at 100–200 V are used.

When cold, the contents of the furnace are removed and sorted according to their various natures, the central mass of re-crystallized fused alumina being the desired product.

In order to obtain a satisfactory abrasive material, large furnaces must be employed, and at the Norton Company's works masses of corundum each weighing five tons or more are regularly obtained. When such large masses are cooled they develop cleavage planes, and by splitting the mass along these, the crushing is facilitated. In the best type of furnace, the hearth can be lowered gradually during the fusion, and by this means a much larger quantity of alumina can be fused than when a fixed hearth is used.

The more slowly the product cools, the better are the crystals and the greater the toughness and abrasive power of the product. Hence, by regulating the temperature and rate of heating and cooling, the hardness and toughness of the mass and the angularity of the particles formed when

it is crushed can be varied. By this means a product with different " tempers " is secured.

An alternative method—patented by G. Dollner in 1897—consists in igniting a mixture of metallic aluminium with various oxides, whereby the product attains so high a temperature that partial fusion of the resultant alumina occurs. A product formed in a modification of this process is known as *corubin*, which is picked out of the slag produced in the manufacture of metallic chromium by the Goldschmidt Thermit process.

**Preparation of Carbide Abrasives.** Silicon carbide (carborundum, etc.) is made by heating a mixture of sand, crushed coke, sawdust, and salt in an electric furnace.* In the centre is a core of granular coke, and around it is placed the mixture of materials to be heated. When the current is switched on, it passes through the carbon core, which offers such a resistance that it becomes intensely hot, thereby heating the coke-silica mixture sufficiently to reduce the silica to silicon and cause it to combine with the carbon. The sawdust rapidly chars and is converted into wood charcoal which combines with some of the silicon. The gases evolved from the charring sawdust keep the whole mass very porous and facilitate the process of carbide formation. The salt fuses at an early stage of the heating and assists in the formation of glassy or slag-like materials which flow downwards and tend to carry the impurities with them.

* *See also The Electric Furnace*, by F. J. Moffett, uniform with this volume (Pitman, 2s. 6d. net).

Owing to the intensely reducing conditions, any iron compounds present are reduced to the metallic state and some of the silica and impurities are volatilized.

In this process, the contents of the furnace are not fused directly, but the heat resulting from the combination of the carbon and silicon is sufficient to form crystals of the carbide which is required as an abrasive. In order to produce crystals of good quality and size it is necessary to use very large furnaces and to occupy about 36 hours for each "run." The consumption of electricity averages about 70,000 h.p.-hr.; the supply is initially 6,000 A at 190 V, but after about 4 hours running, the voltage may be reduced to about 125 V. The temperature attained is estimated at over 3,000° C.; some of the published figures relating to the temperature reached are little more than "wild guesses."

When it is judged that the contents of the furnace have been heated sufficiently, the current is switched off and the furnace is allowed to cool. The contents are then removed carefully, each product being kept separate.

The colour of carborundum crystals varies from black, dark brown, and pale green to various shades of blue and purple, so that a mass of them presents a beautiful and striking appearance. The colour appears to be due solely to the state of oxidation of some of the impurities in the material and is of no commercial importance. The idea that the pale green crystals form the best abrasive has been shown to be incorrect.

## CRUSHING ABRASIVE MATERIALS

Natural abrasives, like emery and corundum and artificial ones made in the electric furnace, are obtained in large masses, some of which weigh several tons each. To reduce these to a convenient size for grinding and cleansing, very powerful crushing machines are employed. The masses are first examined by a skilled workman who chops off any obvious impurities, and by paying due attention to the cleavage planes of the mass he is able to break it by heavy blows from a sledge-hammer. These pieces are then reduced to a smaller size by means of a power-driven crusher.

Two types of crusher are in common use, viz.—

(i) *Jaw-crushers*, in which the material is passed between two plates or jaws of specially hardened manganese steel, one of these jaws being fixed and the other having a slight to-and-fro motion. A powerful flywheel stores up energy during its rotation and delivers it to the moving jaw, thereby applying a very powerful pressure to the material to be crushed.

(ii) *Gyratory crushers*, in which the material falls between two cones, one of which rotates rapidly.

As abrasive materials are extremely hard and difficult to crush, a series of crushing machines is sometimes employed, the material passing through each of these in turn. The cost of repairing the machines is heavy for they must be kept in good working order, or the waste of power is enormous.

## CLEANSING ABRASIVE MATERIALS

Both natural and artificial abrasive materials must usually be separated from adherent impurities; this is known as "cleaning," and it may be effected either before or after crushing, or the material may be cleaned, then crushed and cleaned again, according to the nature of the material and of the impurities present.

**Cleaning Aluminous Abrasives.** Corundum, emery, and other aluminous abrasives are usually cleaned by passing the coarsely crushed material over magnetic separators and then over classifying tables similar to those used in other metal-mining industries. The essential principle underlying the cleaning process is that if a mixture of substances of different specific gravities is subjected to the action of a current of water flowing at a carefully regulated rate, the solid particles being kept separate by vibration or other simple means, the "light" particles will be carried away by the water whilst the heavier ones settle and remain behind. The older process of washing the material in a stream of water was not efficient enough for modern requirements, but various improvements which have been made in it result in a very well-cleaned product.

As corundum crystals have smooth edges to which the binding material used in grinding-wheel manufacture does not readily adhere, the crushed crystals are sometimes subjected to a further cleaning process, which consists in heating them to a temperature of about 600° C. in sodium or potassium hydrogen sulphate ("nitre cake")

which has a powerful corrosive and solvent action on the corundum and on its impurities, the former being thereby roughened and the latter removed by solution. After this heating, the particles are washed thoroughly with water and are then dried.

**Cleaning Carbide Abrasives.** Carborundum and other carbide abrasives are crushed to a coarse powder and washed with strong sulphuric acid which dissolves any adherent iron oxide. The crystals are next washed thoroughly with water and then dried.

**Cleaning Powders by Elutriation.** Pumice, rouge, and other abrasive powders are cleaned by a process known as elutriation, which consists in subjecting them to a stream of water the rate of flow of which is carefully regulated so as to carry off the particles required for use, whilst the largest and coarsest particles sink and remain behind. The water containing the very finest particles is run into large vats where it remains stationary for several days (or weeks) until the particles have settled ; the clear water is then run off and the residue dried ready for use. The process is slow, tedious and by no means as satisfactory as could be desired. Recent improvements in centrifugal separators* have shown that these appliances afford a superior means of cleaning fine abrasive powders, but their use commercially for this purpose has only just begun. The employment of centrifugal separators for removing water from larger particles has long been known.

* *See also Filtration*, by T. Roland Wollaston, uniform with this volume (Pitman, 2s. 6d. net).

## GRINDING ABRASIVE MATERIALS

The crushed abrasive material must usually be reduced to powder before it is fit for use, though some abrasives, such as diamond, corundum, and carborundum, are employed in the form of particles $\frac{1}{8}$ in. or more in diameter. The crushing is usually effected in edge-runner mills, which consist of a circular pan with a bottom of hard manganese steel surmounted by a pair of vertical grinding wheels, the rims or tyres of which are also made of hard steel. The material is placed on the pan and the grinding wheels or runners reduce it to powder, whilst scrapers pass the uncrushed material beneath the grinding wheels and take the crushed material to a perforated part of the pan through which it falls into a " well " beneath. By this means, the material is removed from the mill as soon as it has been ground sufficiently fine. In most grinding mills of this type used for abrasive materials, the pan is stationary and the runners are mounted on a horizontal shaft attached to a vertical one which is rotated by a crown wheel and pinion, so that the runners follow each other around the pan. An equal output is obtained with the expenditure of less power by making the pan revolve and mounting the runners on a fixed shaft, and these " revolving pan mills " are now replacing the older " chaser mills " in modern works.

For the finest powders, ball- and tube-mills are also used. These consist of a revolving drum containing the material to be ground and also a large quantity of steel balls or globular masses of

abrasive. As the drum revolves these masses are lifted and then fall, beating the material beneath them until it is reduced to fine powder.

In a well-designed crushing plant, a series of mills is used, a jaw-crusher being employed to reduce the material to pieces 2 in. and less in diameter, edge-runner mills to reduce it to a moderately coarse powder, and either enclosed edge-runner mills or ball- or tube-mills to reduce it to a fine powder. Various other types of grinding mill are used in some works, but they are not extensively employed for grinding abrasive materials.

*Diamond dust* is prepared by crushing " bort " in a small mortar—the bort being very brittle and readily reduced to powder by repeated blows. The product is graded by stirring it with oil and pouring off the latter after ten minutes, and repeating the treatment with gradually increasing intervals. The following grades of diamond dust are thus produced—

| | |
|---|---|
| After 5 minutes' settlement . | Grade No. 0 |
| „ 10 „ „ . | „ 1 |
| „ 30 „ „ . | „ 2 |
| „ 1 hour's „ . | „ 3 |
| „ 2 „ „ . | „ 4 |
| „ 10 „ „ . | „ 5 |
| Remainder . . . . | „ 6 |

## GRADING ABRASIVE MATERIALS

The process of separating a ground abrasive material into particles of various sizes is known as *grading*, but the size of any given particle is known as its *grit*. The use of the word *grade* to indicate the degree of hardness of a block or wheel made of abrasive material is liable to lead to confusion,

but it is too well established in the trade for it to be lightly abolished.

**Grading by Screens.** The process of sizing or grading is necessary in order that the abrasive may be really suitable for the purpose for which it is to be used. For all but the finest abrasives ("flours"), grading is effected by a series of riddles, sieves or screens, the coarse and medium screens being made of perforated steel or phosphor bronze gauze, whilst the finest are made of silk. With recent improvements in making fine bronze gauze, the use of silk lawns is rapidly diminishing.

The screens are usually in the form of long troughs, the bottom of which is made of perforated sheet or gauze. The material is placed at the upper end and flows down the screen, the fine particles passing through and the coarse ones passing away over the lower end. The apertures in the screen vary from six meshes to 200 meshes per linear inch, twenty grades of abrasive being produced. These are distinguished by the number of the screen to which they correspond, the screens being numbered according to the number of apertures or meshes per linear inch, viz., 6, 8, 10, 12, 14, 16, 20, 24, 30, 36, 40, 50, 60, 70, 80, 90, 100, 120, 150, 180, 200.

Thus, a No. 24 abrasive is one the grains of which have passed through a 24-mesh screen, but are too large to pass through the next finer screen, which has 30 holes to the linear inch.

The standard for screens which is usually adopted is that of the Institute of Mining and Metallurgy, which specifies that the diameter of

the wires forming the screen must be exactly equal to that of the aperture. Unless the size of the wires is specified, the "number" of the screen has no definite value, and the results from non-standardized screens are not comparable. If such a screen is made of coarse wire, the particles will be fine; whereas if thin wires are used, larger particles will pass through the screen for the same number of meshes per linear inch. It should be observed that the size of the largest particles of a given "grit" or mesh is slightly less than that of the aperture in the screen. If the standard screens mentioned above are used, the reciprocal of the number of the mesh is twice the diameter of the largest particle,* because the aperture and the wires are of equal diameter. If other screens are used, the size of the particles cannot be stated unless the size of the aperture is correctly known.

Revolving, vibrating and various other types of screen are used, but these additions are intended merely to increase the output and do not affect the general principle on which the screens work.

In order to separate the abrasive material into the desired series of sizes or grades a corresponding number of screens must be used. The product should be tested frequently as the screens wear rapidly and then do not serve their purpose.

**Grading by Sedimentation.** It is not practicable to use finer screens than those with 200 meshes per linear inch, so that in order to separate the

* i.e. $\frac{1}{N} = 2A$ (or $2AN = 1$), where $N$ = the "number" of the screen and $A$ = the diameter of each aperture.

finest grades of abrasives—usually known as "flour" and designated by letters, ciphers or numbers, such as F, FF, FFF, and FFFF, or 0, 00, 000, and 0000—a process of elutriation is employed. Some of the flours are known by numbers which indicate the time they require to settle when suspended in water ; thus a 60-minute powder is one which has settled out of suspension in 60 minutes. Unfortunately, this designation gives no real clue to the size of the particles unless the depth of the liquid in the settling tank is known. Usually it is about 3 ft.

In the process of elutriation, the powder is stirred violently with water, to which a little soda is sometimes added, and it is then either : (i) allowed to settle for a few minutes after which it is poured off and allowed to settle for a further period, run off again, and again allowed to settle, the process being continued indefinitely as the particles of various grades are collected in the various vessels ; *or* (ii) the abrasive, suspended in water, is allowed to flow slowly through a series of tanks, each one in the series being of greater diameter than the preceding one. By this means the rate of flow of the liquid is reduced progressively and the particles of abrasive are deposited according to the rate of flow and their own size.

The residues in the various vessels are collected separately, dried, and are then ready for use. The times of sedimentation or the rate of flow must be controlled carefully and the vessels must always be of the correct size, or the grading will be irregular, as it depends wholly on the rate at which

particles of any given size will settle out of suspension and this rate depends on the depth of the settling vessel or on the rate of flow of the water through it.

Whereas emery can be graded most satisfactorily by elutriation or decantation with water, these processes cannot be used for the finest grains of carborundum flour as this material, when beyond a certain fineness, entangles air to such an extent that a certain amount of coarse powder persists among the finest particles. If alcohol is substituted for water a much better separation is effected. The makers supply grits which are quite satisfactory except the finest; thus, the 15M, 30M, and 100M flours (to take the last degrees of fineness) are very satisfactory so far as they go; but 100M is hardly fine enough for the final grinding of a first-class speculum. Examination of these fine flours under a microscope reveals at once the extraordinary uniformity in size of grain in each separate grit and reflects credit on the care of the makers in the process of grading, but the finest grit of all (100M) has a different appearance. The grains of which it is composed do not seem to be much finer than those in the previous fraction (30M); there is less uniformity of size, and there is present, mixed with the coarser 30M particles, a quantity of dust which is very fine indeed, so fine that a 1 in. objective only shows it as consisting of shapeless dots. If this material could be separated, it should prove to be a very fine finishing powder, but it is a most elusive material, and it does not appear to obey the ordinary laws of sedimentation. It is probably somewhat colloidal in character and partakes more of the nature of minute particles of mineral jelly than of what are commonly regarded as solid particles. This material has never been fully investigated, and as the subject of colloidal particles is too large to be discussed in this primer, it must suffice merely to indicate that it is probably colloidal in character.

There is no wholly satisfactory method of separating it from the coarser (but still very fine) particles with which it is associated, though minute quantities may be obtained by shaking up 100M flour with alcohol in a tall bottle, allowing it to stand for several days, pouring off the liquid, and scraping off the extreme surface of the sediment with a strip of metal. Even then, some of the

coarser powder is always included and the quantity of the finest material obtained is not sufficient to enable the process to be used commercially.

**Grading by Air Current.** The finest particles of abrasive and mica, etc., are sometimes separated at an early stage in the screening by dropping the material into a funnel through which a regulated current of air is passed. The air carries off the finest particles, and the coarser ones settle and pass out through trap doors.

The action of such a device is often improved by inserting a revolving disc on to which the material falls, prior to separation, and one or more fans which ensure the uniform motion of the air through the "air-separator."

**Packing.** The graded material is dried, if necessary, and placed in bags, each holding about 100 lb. of material and clearly marked to show the nature and grade of the contents, or it may be stored in bins until required for use. In some works, the materials from the first series of grading operations are sent to a "finishing" department, where materials from different sources or furnaces are mixed and re-graded so as to give a more uniform material and prevent any mistakes made in the first grading from damaging the final product.

## CHAPTER IV

### MANUFACTURE OF ABRASIVE BLOCKS, WHEELS, ETC.

THE manufacture of abrasive blocks, rubbing stones, sharpeners, grinding wheels, etc., is now a very important industry. Such articles may be

produced *either* by cutting or turning natural blocks of material to the desired shape, *or* by mixing graded particles of abrasive material with a suitable binding agent, moulding the mixture to the required shape, and fixing the binder by baking or other suitable treatment.

Skilled masons are required to shape natural blocks. The process is costly and not wholly satisfactory so that, with the introduction of artificial abrasives, it has become more common to produce the desired articles by moulding. Large grinding wheels (5 ft. or more in diameter) are still made of natural stone as it is, at present, impossible to rely on moulded wheels of more than 4 ft. 6 in. diameter except for a few special purposes.

Notwithstanding the amount of labour involved in cutting wheels and blocks of natural stone, they are usually cheaper than artificial ones in first cost, but when the cost of mounting and dressing, and the slow speed of working are taken into consideration the apparently cheap natural stones are generally the more costly.

The so-called "artificial" grinding wheels, blocks, etc., are chiefly made from carefully graded abrasive materials by the use of one of four types of bonding agents: viz., rubber, shellac, silicate, and vitrified bonds, the first two being sometimes also known as elastic bonds.

Some of the first moulded grinding wheels were made of a mixture of emery and Sorel cement (a mixture of magnesia and magnesium chloride) in the proportion of 15 to 20 per cent of the cement and 80 to 85 per cent of the abrasive. The materials are mixed with water to

form a soft paste and this is shaped by placing it in iron moulds and tamping it lightly. Heavy pressure is considered unnecessary or even harmful. The moulded articles are exposed to the air for two or three days, after which they are turned true to shape and then allowed to stand for a week or more to complete the hardening. On account of the low cost of manufacture, such wheels are still made, though in diminishing quantities, as they are seriously affected by water, and so cannot be used for wet grinding. Moreover, they are not so reliable as wheels made with a rubber, shellac, silicate or vitrified bond.

**Rubber-Bonded Wheels.** In the manufacture of these wheels, graded abrasive and carefully selected crude rubber in small pieces are mixed in a dry state, and the mixture is passed between a pair of steam-heated rolls so as to form a ribbon. This ribbon is passed through successive pairs of rolls until the abrasive is thoroughly embedded in the rubber and the final ribbon is then laid on a table and discs or other shapes are cut out of it with a cutting tool similar to that used by pastry cooks, or with a sharp knife.

Some manufacturers mix the rubber with oil or other solvent and heat the mixture until a "solution" is obtained. The liquid is then allowed to cool somewhat and is mixed with flowers of sulphur or other vulcanizing agent, a little colouring matter being sometimes added. This binding material and the abrasive are then thoroughly mixed in a steam-heated mixer so as to form a sticky paste which must be moulded whilst still warm. The moulding is effected in the same manner as with vitrified wheels, but the pressure is greater (about 2,800 lb. per sq. in.) and must be maintained for several minutes. For smaller

articles the paste may be passed between rolls and cut out, as previously described. The moulded or cut-out article is placed in a metal case (weighted, if necessary, to prevent warping), and is then vulcanized by heating it in a suitable stove at about 150° C. for 24 hrs., whereby the soft rubber is converted into hard vulcanite. The heating may be effected by coal, gas or electricity, and some makers prefer steam at a pressure of about 90 lb. per sq. in.

The baked articles are allowed to cool and, in the case of wheels, are then turned true to shape with a diamond dressing tool.

**Shellac-Bonded Wheels.** These are made by mixing the abrasive powder with finely-ground shellac in a dry state, and transferring the mixture to a hot mould where it is subjected to pressure. The heating is continued until the shellac has melted sufficiently to unite the particles of abrasive. The pressure is then released and the articles are baked in an oven at a slightly higher temperature so as to complete the bonding process.

For small articles the cold mixture of abrasive and shellac is sometimes placed in an iron mould and tamped, rolled or compressed with an iron-shod tool. The very fragile articles are then baked at a temperature just sufficient to make the shellac viscous, the heating being continued as long as is considered necessary.

The proportion of bond required is usually from 5 to 7 per cent of the weight of the abrasive, but larger proportions are sometimes employed.

In some cases the binding agent does not consist of shellac but of "boiled linseed oil," to which a varnish resin or gum has been added so as to produce a sufficiently viscous mixture. Rubber and flowers of sulphur are sometimes added for the same purpose. The materials are mixed so as to form a paste which may then be passed between rolls so as to produce a ribbon which is afterwards cut into wheels, or the mass may be shaped in moulds. The binding agent is hardened by baking the articles for about 12 hrs. at 120° C., allowing them to cool down during the night and then reheating at 170–180° C. for a further 12 hrs. The time and temperature must naturally vary according to the binding agents used.

The great advantage of shellac over all other bonds is the elasticity which it imparts to the wheels in which it is used.

**Silicate Wheels.** As the name implies, silicate wheels are made by using a bonding material composed of silicate of soda in the form of water-glass or of "crystal-" or "rock-silicate." They are made by mixing the abrasive and silicate with water, placing the wet pasty mixture in an iron mould, and tamping or compressing it. For some unknown reason, mechanical tamping does not appear to be satisfactory.

Silicate wheels made by the dry process or under great pressure have not proved to be so sound as those made by hand from a soft paste.

The wheels are dried and are afterwards baked at a dull red heat. This process of manufacture is specially used for grinding-wheels more than 30 in. diameter, which are very difficult to make with a vitrified bond.

More recently the Carborundum Company has patented the use of a mixture of abrasive with sodium silicate and zinc oxide as bond. The

materials are made into a paste, which is shaped in iron moulds and the articles, after drying, are heated in a kiln to a temperature sufficient to fuse the silicate of soda and cause the formation of an insoluble double silicate of sodium and zinc. The firing temperature is preferably from 850° to 1,100° C.

A silicate bond is used largely by small firms engaged in the manufacture of abrasives, as it requires comparatively little machinery, and is free from most of the difficulties involved in the manufacture of vitrified articles. As the baking temperature for silicate wheels is quite low, impure abrasives (which would fuse at the temperature required to bake vitrified wheels) can be used satisfactorily with a silicate bond. Abrasive wheels, etc., made with a silicate bond can be made and finished in a few days, whereas wheels with vitrified bonds require several months. Silicate-bonded wheels can be made of any size. The harder grades of silicate wheels are less free-cutting than vitrified wheels of the same grades, but the softer grades cut very freely. Silicate wheels are very close in texture and are chiefly used for wet grinding, as they are not readily affected by water.

**Vitrified Wheels.** For this type of wheel the abrasive is mixed with clay, felspar or other binding agent, which forms a vitrified or glassy mass when heated. The maker weighs out a suitable quantity of abrasive, selecting the materials so that its particles are of suitable diameter (i.e. of suitable "grit") and, if necessary, mixing material of various sizes in suitable proportions. To the abrasive is added a suitable (weighed) proportion of bonding agent and usually a measured quantity of water. A little water-glass (sodium silicate) is sometimes added to the water so as to form a bond prior to the articles being burned. These materials are then thoroughly

mixed in a power-driven mixer. The mixture is shaped in moulds—usually under pressure—and the resulting articles are dried and burned. When cool, they are dressed accurately to shape and the larger ones are carefully "balanced" before being sold.

MIXING AND MOULDING. Three methods of mixing and moulding the materials are employed—

(i) *Dry mixing*, in which little or no water is used and the damp powder is shaped by the application of great pressure to the mould. The mixing is effected in a tumbler or cylinder mill, the moulds are filled with the powder, which is then subjected to a hydraulic pressure of 2 tons per sq. in. Abrasive articles made by the dry process are compact but not necessarily hard, and there is always a tendency for the pressure to have been distributed unevenly (owing to entrapped air). This process is used chiefly where dense articles of moderate toughness are required.

(ii) *Wet mixing*, in which sufficient water is used to produce a soft paste or "slop" which is placed in a mould and tamped with a hand-tool or rammer. This process is sometimes known as "puddling." The paste must not be too soft or the articles made from it will be difficult to draw from the moulds, will break too easily, and will be of irregular density and so will easily damage the edge tools to which they may be applied. The paste is placed in an iron or steel mould and the latter is then dried slowly in a steam-heated chamber. The drying requires several weeks in the case of large wheels. Sometimes a stiffer paste is prepared and after placing it in the mould it is tamped by hand or compressed hydraulically so as to make the mass compact, after which it is dried carefully. The dried wheels are then turned true to shape on a special form of lathe known as a shaving machine.

(iii) *Combination mixing* in which a wet paste is prepared and moulded, the article is then allowed to stiffen, and is afterwards re-moulded under pressure. The moulds are made of iron or preferably steel, as they have to withstand considerable pressure. For wheels, each mould consists of a circular rim, into which are fitted two plates and a central rod or core. The lower plate is placed at the bottom of the mould and the latter is filled with the

mixture to be moulded. The upper plate is then placed in position and the mass is consolidated by tamping or ramming the upper plate. Some manufacturers place only a small amount of material in the mould, tamp it, add another portion of material, tamp that, and continue "building up" the mass in this manner until the mould is full. The upper plate then merely serves as a convenient means of handling the mould and its contents without finger-marking the latter.

Re-pressing. The mould with its contents may be subjected to a pressure of from 560 to 700 lb. per sq. in. in a power-driven or hydraulic press, after the moulded article has been allowed to stiffen or "set." This re-pressing is objectionable as it tends to separate the particles in one direction and compress them in another (thereby altering the texture of the mass), after it has begun to stiffen. By pressing the freshly moulded paste, this objection is overcome. The pressure should be applied from above and below, as a one-sided pressure gives unsatisfactory results. It is also desirable to press the article twice and to allow any entrapped air to escape before the second pressure is applied.

Drying. The articles are allowed to stiffen and are then dried at a temperature of from 100° C. to 120° C. in stoves through which a gentle current of air circulates. The drying period in the stove is usually about 24 hrs.

Burning. After being dried and trued to shape the articles are burned in a kiln similar to those used for bricks and pottery, to a temperature of about 1,300° C. to 1,450° C. The kilns used for burning abrasives with a vitrified bond were formerly circular (about 16 ft. internal diameter and 29 ft. high internally and 60 ft. externally) and of the down-draught type, but these were wasteful in fuel and the larger works have now abandoned them in favour of continuous-chamber kilns heated by producer gas; the waste gases from one chamber pass to several other chambers in succession and so reduce the amount of fuel required to about one-third that needed when separate kilns are employed. Large chambers are not satisfactory as they are very difficult to heat uniformly at the high temperatures attained in this industry, but chambers 16 ft. by 9 ft. by 9 ft. internally are quite satisfactory. The goods are placed in the kiln in circular cases made of burned fire-clay and known as "saggers." On the bottom of a sagger is placed a little

fine sand forming a layer about $\frac{3}{4}$ in. thick. On this is placed a wheel or other article to be fired and it is moved to and fro so as to ensure its being properly "bedded." A second portion of sand is placed on the wheel and this is followed by a second wheel, this procedure being continued until the sagger is full. A fireclay plug is usually placed in the holes in the centre of the wheels to ensure the latter retaining their shape. Some manufacturers do not use ready-made saggers but build the saggers in the kiln, using flat bottom discs of burned fireclay and segmental sides of the same material.

The saggers are piled one on another until the kiln is full. In the large continuous kilns, now used in this industry, the wheels are kept for about three weeks, during which time waste heat from one chamber passes in to succeeding chambers, so that the fuel consumption is relatively low. In these continuous kilns the wheels are being heated for about 8 days and cooled during about 15 days. These slow times of heating and cooling are essential for the production of articles of good quality, and undue haste in this part of the manufacture results in the production of a defective bond.

Small wheels, cylinders, etc., are sometimes burned in muffles of about 1 cu. yd. capacity as they do not require so prolonged a firing, but may be burned and cooled in from four to six days, whereas larger articles require a fortnight or three weeks.

The burning of abrasive articles with a vitrified bond is a delicate matter requiring great skill, as an error of 20° C. in the final temperature may spoil the articles. The burning is usually controlled by means of Seger cones, which are small pyramids of fusible material which bend over when they have been heated for a sufficient length of time to the temperature which they are supposed to indicate.

The temperature must be raised very slowly until the finishing point is attained, and the cooling should be equally slow or the articles will be cracked, and not merely useless, but actually dangerous to use.

The final temperature attained in most kilns is between 1,300° C. and 1,350° C. (Seger cones 10 to 12), from 90 to 102 hours being required to attain it, after which the kiln is maintained at the maximum temperature for at least an hour, in order that the whole of the contents may be burned properly.

When the burning is complete (as judged by the Seger cones, the appearance of the fire and by the examination of "trials" withdrawn from the kiln) all openings into the kiln are closed and it is allowed to cool slowly for about 14 days. When properly burned—

(i) An emery wheel is light brown.

(ii) A corundum wheel is reddish, but if made of artificial corundum it will probably be yellow.

(iii) A carborundum or carbide wheel is black with a greenish tinge.

It is generally considered that the more porous the wheel, the better is its quality, and that a candle can be extinguished by blowing through a good wheel.

Owing to its hardness, the vitrified bond is itself an abrasive and so assists in the cutting or grinding. It is unaffected by water, acids, oil, etc., and by heat and cold and the porosity of the wheels makes them very free-cutting.

The production of vitrified wheels involves great skill and attention to detail. For instance, the drying must be conducted carefully or the articles will crack. Similarly the burning must be controlled with equal care and skill. Even with the greatest care it is almost impossible to produce reliable wheels more than 36 in. diameter if they have a vitrified bond.

**Finishing Operations on Wheels, etc.** *Sorting.* As the wheels are taken out of the kiln they are examined for cracks, etc., and are tested for soundness by striking them sharply, when they should emit a clear, ringing note. They are next sorted according to the grit and grade, these being indicated on the unburned wheels by certain marks made by the moulder.

*Checking the Grade.* The next stage of inspection is known as "checking the grade" or as "grading,"

and its object is to ensure that the product has the precise hardness and toughness or " grade " (p. 40) required. The test consists in " jabbing " the abrasive article with a short, wide screw-driver, and by constant practice an inspector is able to judge the grade by the sound emitted and by the amount of force required to separate particles of abrasive.

Various mechanical means have been devised for grading abrasive wheels, etc., but in practice they are less satisfactory than an experienced inspector with the simple tool just mentioned.

*Mounting.* After being sorted, the wheels are " bushed " by fitting a mandrel or core of suitable size into the central hole and filling the intervening space with molten lead or a suitable alloy. By this means the wheels are made ready to fit on any shaft of specified size and the user is saved the trouble of fitting a special bush.

*Dressing.* After being fitted with a bush the wheels, etc., are placed in a lathe and turned true to shape by means of a diamond or a dressing tool, consisting of three or more wheels of specially hardened steel mounted on a handle (*see* Fig. 11, p. 111). Conical dressing tools are particularly useful for trimming the interior of cylinders, rings, etc. All lathes used for dressing abrasive wheels, etc., should be connected to an induced-draught dust-extracting system to carry away the particles of dust which might, otherwise, injure the dressers.

*Balancing.* The wheels are then placed on a

balancing stand and carefully tested in various positions. If any part of the wheel is too light, so as to throw the wheel out of balance for a given position, a weight is attached in such a manner as to counteract this deficiency or, if the amount of correction is very large, the wheel is rejected or the defect is eliminated by turning the wheel to a smaller diameter or thickness.

The proper balancing of modern grinding wheels is very important as they are run at high speeds and if out of balance might cause a very serious accident. An ill-balanced wheel is very liable to break, and even before this occurs it is impossible to obtain accurate results with an ill-balanced wheel.

*Testing.* Before an abrasive wheel, cylinder or ring leaves the maker's works it should be tested by revolving it at twice its normal speed in a specially strong casing, which will collect all the fragments should the article break.

*Labelling.* In order to reduce the risk of damage through faulty mounting, abrasive wheels are usually fitted with a cardboard disc at each side, and on this are shown the nature, number, grit and grade of the wheel, and the maximum speed at which it may safely be driven.

**Abrasive Blocks, Hones, etc.** Abrasive blocks, artificial hones, sharpening stones, and " rubbers " are made by the same processes as are used for grinding-wheels, silicate and vitrified bonds being the most largely used. Makers who prefer to shape these stones under pressure, naturally use a vitrified bond.

Sharpening stones are designated as follows—

*Coarse :* with a No. 120 grit abrasive.

*Medium :* with a No. 180 grit abrasive.

*Fine :* with a flour abrasive F to FFF or equivalent (p. 43).

A useful form of rubbing stone for sharpening scythes, and other cutting tools is made from one part of good fat pipeclay, well washed ; one part of fine white sand ; and three parts of emery, well washed, and sifted. These ingredients are well incorporated, moulded, dried and subjected to a bright yellow heat for three hours. For a harder stone, up to three parts of powdered French chalk is added. Attention must be paid to the burning ; blocks which are properly fired are good, but those which are over-fired, i.e. too highly vitrified, are of little use. Greatly under-fired blocks wear away rapidly and are too soft to sharpen tools well.

## CHAPTER V

### MANUFACTURE OF ABRASIVE PAPERS AND CLOTHS

ABRASIVE cloths and papers of all kinds were made originally by coating any convenient cloth or paper with glue and then sprinkling on an excess of the abrasive whilst the glue was still hot. The surplus abrasive was removed, when the glue had set, by inverting the paper or cloth and tapping it gently.

At the present day, mechanical coating appliances are used in which a band of paper or cloth, travelling rapidly, passes between a series of rollers in such a manner that the glue applied to its upper surface is spread uniformly over the cloth or paper. The band next passes beneath a hopper from which flows a steady stream of the abrasive, in rather larger quantity than is needed to coat it. The band of paper or cloth is then carried over further rolls and cross-sticks, during which movement the excess of abrasive falls away, and a second coating of glue is applied to the band. The paper or cloth then travels through a long drying chamber, heated by a current of air, and is afterwards wound on rolls. As each roll is filled it is taken off the winding machine and removed to the store, where it is kept until the glue hardens after which it is cut into pieces of the requisite size and shape.

Recently, endless bands of abrasive cloth have become popular. They are best made of cloth woven all in one piece so as to avoid awkward joints. The bands are then mounted on rolls, and the glue and abrasive are applied as described in the preceding paragraph. Such bands cost more to produce than plain strips or rolls of cloth, but the absence of a joint is a great advantage which fully justifies the higher price.

The abrasive and grit are chosen according to the purpose for which the paper or cloth is to be used. The combinations specified in Table I are largely employed.

TABLE I

ABRASIVES AND GRITS FOR PAPER AND CLOTH

| *Abrasive.* | *Grits.* |
|---|---|
| Emery on paper . . . | From FF to 24 mesh |
| „ „ cloth . . . | „ FF „ 24 mesh |
| Carborundum on paper . . | „ FF „ 20 mesh |
| „ „ cloth . . | „ FF „ 46 mesh |
| Garnet paper for finishing woodwork | „ FF „ 50 mesh |
| „ „ „ cabinet work . | „ FF „ 20 mesh |
| Sand paper . . . . | „ F „ 20 mesh |

Many manufacturers of abrasive cloths and papers have their own numbers for identifying the various grits or sizes of particles, but it is desirable that users should ascertain the mesh corresponding to such private numbers. In order to do this, the abrasive may usually be separated by boiling the cloth or paper with several changes of water; after being rinsed, the abrasive may be dried, sifted, and its true grit determined. Various tables of comparison have been published, but most of those tested by the author have been found to be incorrect.

When testing abrasive paper or cloth from a fresh source of supply a sample of the material should be placed alongside a sample of the make previously employed and both samples should be used simultaneously. It should then be fairly easy to judge which gives the best results. In more elaborate investigations the tensile strength of the cloth or paper and an analysis and microscopic examination of the abrasive are sometimes necessary.

## CHAPTER VI

### POLISHES

POLISHES are employed to render a surface smooth and reflective. They may be divided into two groups—

(*a*) Materials which form a smooth coating over a rougher surface, e.g. boot and furniture polishes.

(*b*) Materials of an abrasive nature, which owe their polishing effect to their ability to remove projections from the rough surface and to fill up any hollow portions in the material to be polished.

In polishes of the first group the action is not of an abrasive character, the reflective power, " gloss " or " polish " on the article being chiefly a property of the coating and not of the article beneath. In this chapter only the abrasive class of polishes is considered as the others partake more of the nature of lacquers than of true polishes.

**Composition of Polishes.** The ingredients of an abrasive polish must not leave any appreciable scratches on the work and must, therefore, be in a finely-divided state, consequently the choice of material is comparatively limited.

The materials most generally employed as fine abrasives are : fine sand, Tripoli powder, rottenstone, kieselguhr, bath brick (a variety of burnt silt), fine emery, pumice, lime, whiting. and chalk. Notes on most of these materials are given in Chapter II.

The abrasive need not necessarily be in the solid state but is usually mixed with a liquid or grease

so as to form a fluid or paste in which the abrasive is suspended. It is frequently of considerable advantage to mix the abrasive with a detergent, such as paraffin, or a solution of soap, so that the article is cleansed as well as mechanically abraded. The use of oxalic acid is not usually desirable, though it is present in some well-known metal polishes.

A typical composition for a *paste metal polish* is as follows—

| | |
|---|---|
| Powdered oxalic acid | 1 lb. |
| Levigated red iron oxide | 25 ,, |
| Rottenstone | 10 ,, |
| Palm oil | 30 ,, |
| Castile soap | 4 ,, |

In such a paste, the iron oxide and rottenstone act as abrasives, and the particles being minute and of only moderate hardness, they do not produce large scratches on the work. The palm oil and soap act as media in which the abrasive is suspended, whilst the oxalic acid has a detergent action.

A typical *liquid metal polish* consists of—

| | |
|---|---|
| Soap flakes | 1 oz. |
| Rottenstone or other suitable form of silica | 4 lb. |
| Methylated spirit | ½ pint |
| Paraffin | 1 gallon. |

This polish—which is of an abrasive nature—may be compared with the following *furniture polish*, which is of an entirely different character—

| | |
|---|---|
| White soap | 12 oz. |
| Boiling water | 120 ,, |
| White wax | 8 ,, |
| Beeswax | 1 lb. |
| Spirit of turpentine | 4 ,, |

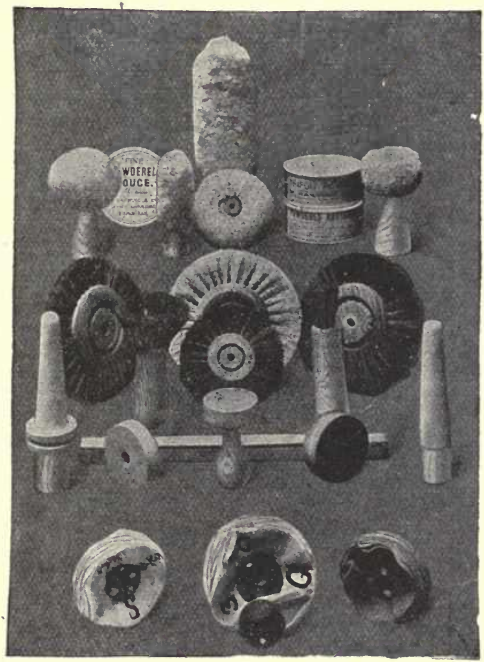
The waxes should be melted and the turpentine added carefully. When a thorough mixture is obtained it is added (whilst still hot) to a solution made by dissolving the soap in the boiling water and then stirring the whole until it cools.

In the preparation of both pastes and liquid polishes the solid materials are intimately incorporated in a mixing mill, and a portion is tested by being passed through a sieve having 80 holes per linear inch. Unless this test shows the mixing to be complete the process is continued as long as may be necessary. Any fluid constituents are mixed together in another vessel with the aid of heat, if necessary, after which the solid materials are added and thoroughly mixed. In some cases better results are obtained by mixing part of the liquid with some of the solid materials in an edge-runner or tempering mill. Thus, where soap is used it should be cut into shreds, added to water, and mixed thoroughly until it is brought into solution prior to adding the other ingredients. To facilitate solution the mixture may be heated.

**Applying Polishes.** Polishes may be applied by hand—the material being spread on a brush, pad, cloth, or other suitable device, and rubbed on to the article to be polished—or they may be applied by mechanical means, the polishing materials being held on a rotating disc of cloth, wood, leather or metal. The disc may be vertical—in which case the polish is applied to its circumference or rim—or horizontal, when the polish is applied to its upper surface. Occasionally horizontal endless belts charged with a polishing paste or powder are prepared for small objects, and are replacing the leather-rimmed wheels which are extensively used for this purpose. A typical selection of polishing wheels and tools is shown in Fig. 3.

Polishing wheels, bands, etc., enable a polish

to be obtained very rapidly, but the final effect is not so fine as that obtained by rubbing with the



*(W. Canning & Co., Birmingham.)*

FIG. 3.—TYPICAL COLLECTION OF POLISHING WHEELS, BRUSHES, TOOLS, ETC.

outer side of the hand, and the latter is always used for the best polishes on silver and gold ware.

**Machine-Polishing.** When a machine is to be employed for polishing, no pains should be spared

in selecting one which will do the work to best advantage. For instance, some machines are adapted to polishing flat surfaces where the edges are required to be very sharp, whilst others are required to polish irregular surfaces where the edges do not matter so much. Each type of machine has its own class of work for which it should be used and a careful consideration of the type required will save much loss after the machines have been installed.

Whichever class of machine is used, it is very important that it should be kept in good condition, the bearings being oiled at frequent intervals, unless automatic lubricators are installed. If attention is not paid to the maintenance of the machine, more time is required to obtain a polish and the finish is not of such good quality.

**Stages of Polishing.** The polishing is usually divided into three stages : (1) roughing ; (2) dry fining ; and (3) finishing, for each of which various grades of abrasive are employed. For the *roughing* process abrasives ranging from No. 20 to No. 80, according to the quality of the work, are used, generally on a dry wheel. For *dry fining*, abrasives from No. 90 to No. 120 are used on a dry wheel, whilst the abrasive for *finishing* is usually carried by means of some liquid or plastic vehicle, such as oil or beeswax. The fineness of the abrasive for finishing depends on the nature of the polish required and varies from No. 150 to the finest grades, whilst the polishing medium may consist of either a hard abrasive in the form of " flour " or a soft powder, such as rouge, slaked

lime, or other material, with a hardness of about 3 or 4 on Mohs' scale.

**Strap or Band Polishing Machines.** In these machines a belt of canvas or leather charged on the outer surface with a mixture of glue and abrasive, is carried on two or more flanged pulleys, as shown in Fig. 4. The belt is charged by coating the belt with glue and passing it forcibly through a trough containing the abrasive powder, the

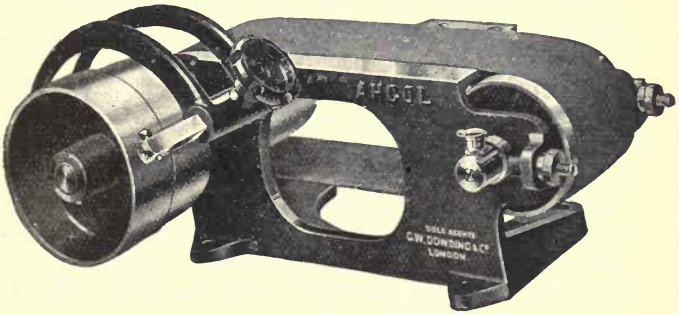



Fig. 4.—Ahcol Band Polishing Machine.

latter being piled up round the belt so as to force the abrasive into the glue. The belt is then hung on pegs until quite dry. The glue should be of good quality and should be heated by steam pipes surrounding the glue-pot so that it is sufficiently heated but is not actually boiled. It should be made fresh each time a belt is charged, so as to ensure the glue adhering strongly to the belt, as old glue is less tenacious. It is preferable to heat the abrasive to the same temperature as the glue before applying it.

Other types of belts sometimes employed are made of paper, but they are not so satisfactory as those made from canvas or leather. Leather belts are more resistant than those of canvas and form a better cushion for polishing.

Polishing is done by pressing the surface to be polished on to the belt whilst the latter is moving at about 2,000 to 2,500 ft. per min. over a flat metal supporting-plate.

Strap-polishing machines are largely employed for brass, cutlery, and jewelry and for some silver and plated goods.

**Glazing Wheels.** These are used intermediately between the grinding and polishing wheels—especially in cutlery manufacture—in order to remove the coarser marks left on the surface of metals after grinding. Glazing wheels usually consist of a wooden centre and a leather rim which is supplied with a moderately coarse emery mixed with glue (*see* next paragraph). When a smooth surface has been obtained, the articles are polished on a similar wheel provided with a much finer abrasive.

**Polishing Wheels.** These are used extensively for fine polishing and "buffing." They usually consist of a wooden disc covered with a leather band fastened to the wheel by glue, aided by wooden pegs. The wooden centre should be so constructed that it is not likely to break; usually it is made in several pieces fastened securely together. The abrasive is fixed by means of glue to the outside of the leather belt rim, and the wheel is rotated at about 5,500 ft. per min. The size of the wheels varies, but the most popular one

is 12 in. diameter, requiring about 3 h.p. to drive it. When fitted with a double coat of leather, these wheels are excellent for finishing purposes and are much used for polishing large flat surfaces when it is essential that the edges should not be rounded. Such wheels are so good that until a few years ago wooden wheels were used almost universally but they are now being replaced by endless bands.

*Cast steel wheels*, about 12 in. diameter and 2½ in. wide, with a strip of canvas or other cloth charged with the abrasive, are very satisfactory for polishing boots and shoes, but less so for cutlery. They are made by placing small squares of cloth or leather edgewise around a steel centre, and the cloth or leather is then compressed sufficiently to retain its position. Such wheels—known as "compressed wheels"—are strong and durable. They are very easily balanced, a property which is very valuable for fine polishing, and on the whole they are much safer than wooden wheels but they are regarded, by users in this country, as inferior to the wheels described in the preceding paragraph. Their chief drawbacks are: (1) they cannot be easily recovered; (2) the position of the leather in these wheels is an unsuitable one, as both the hard and soft sides of the hides are presented simultaneously, whereas when a leather strap is used only the flesh or "cushioned" side is presented; and (3) they are much more easily damaged by cutting than are the ordinary wheels.

*Canvas and Muslin Wheels.* A wheel, consisting of a series of cotton discs mounted close together on the same axle and known as a "mop" or

"dolly" (Fig. 5) is generally used for the preliminary polishing of irregular pieces, such as stoves, shovels, taps, etc., and for silver ware. Such wheels can readily be cleaned when required by means of a "buff stick" or abrasive brick and they are not expensive.

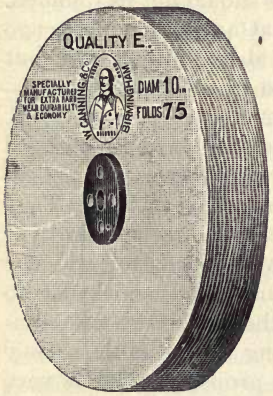



FIG. 5.—COTTON MOP OR DOLLY.

*Hide wheels*, sometimes termed "sea horse wheels," are used for special work, such as the polishing of guns and fine cutlery, but they are very expensive. They are made of walrus hide, which is cut into strips and mounted on a wooden centre, great skill being needed in the selection of the leather. Wheels of this class are usually rotated at a speed of about 7,000 ft. per min.

*Felt wheels* are used extensively by stove makers and others for finishing purposes. They are made of a special kind of coarse felt which is capable of holding large quantities of abrasive and polishing material.

## CHAPTER VII

### SELECTION OF ABRASIVES

THE selection of the best abrasive material for a particular purpose is by no means easy, but it is

worth while to take trouble over the matter. A skilled, intelligent user will generally concentrate his attention on five factors—

(i) The rapidity of grinding or cutting desired or attainable.

(ii) The total amount of work to be performed.

(iii) The finish to be produced.

(iv) The durability of the abrasive article and the cost of replacing it when necessary, including taking down the old appliance, mounting the new one, and getting the latter into running order.

(v) The manner in which the article to be ground and the abrasive are brought into contact, i.e. whether at the face, side, or " corner " of the abrasive wheel, and whether the article is made to pass transversely across the abrasive or *vice versa*, and also the rate of traverse.

In addition to these factors, however, the nature of the abrasive, as well as the size of its particles (or grit) and the nature of the binding agent should be taken into consideration. The general behaviour or grade of the finished abrasive article—whether a block, disc, wheel, etc.—should also be investigated, as some abrasive articles are much more suitable than others for a given purpose.

In the case of grinding wheels, cylinders, and rings the speeds of rotation of the article and of the abrasive must be taken into account as they have a marked effect on the cost and efficiency of the grinding.

The shape and size of the abrasive appliance are also of importance. Thus, a ring or cylinder is sometimes far preferable to a disc, and when

the choice is limited to grinding-wheels a small one may, under some circumstances, be preferable to a larger one, though usually a large wheel is the best, as it costs less in proportion to the amount of work which it will do, it works with less vibration, and it lasts longer without becoming dulled or glazed.

The influences of the variables enumerated are discussed in the following paragraphs.

**Speed of Cutting.** The rapidity of cutting depends chiefly on the coarseness of the abrasive material, the softness or friability of the binding agent, and the speed of rotation. Generally, the speed of cutting may be increased by using a coarser grit, or a softer grade, or by rotating the wheel at a higher speed.

When a grinding-wheel is in use the particles of abrasive cut into the material to be ground and are gradually worn away. Eventually the surface of the wheel would become quite smooth or "glazed," and no further grinding would be possible, if sufficient care had not been taken to select a wheel of such a nature that, as the abrasive particles were worn they were torn out of the wheel, taking with them the adherent bond and exposing a fresh set of abrasive particles ready to continue the grinding.

The time gained by using coarse wheels for roughing may, in some cases, be very great. One traverse may often be taken instead of three or four. Less heat is generated with a coarse, open-grained wheel than with a fine, close-grained one. A good general rule is to use the coarsest wheel which experience shows can be adopted, reserving finer wheels to remove the scratches left by the first. The tendency is also towards the employment of coarser wheels for finishing.

*The total amount of work done* by an abrasive wheel, or similar device, is increased—i.e. the rate of wheel-wear is reduced—by using a finer grit or a harder grade.

**Depth of Cut.** The depth of cut depends principally on the size of the abrasive particles and on the extent to which they can be worn down before they are torn out of the bond. In the case of an abrasive of 80 grit, the average depth of each particle does not exceed 0·010 in., so that if it falls out of the bond when it has protruded half-way the maximum depth of cut cannot exceed 0·004 in., and in practice the deepest cut realized with particles of 80 grit will not exceed 0·001 in. With wheels of 24 grit, the depth of cut can be increased to 0·003 in.

It is impossible to grind accurately to size when the work is held in the hand; it must be held properly by some suitable mechanical means, so as to avoid all undesirable movement.

**Quality of Finish.** The finish produced on the work is improved by using a fine grit, a soft grade, and rotating the wheel or other grinding appliance comparatively slowly. In some cases, the article to be ground may also be rotated with advantage. Coarse, hard and rapidly rotating abrasives cut or grind rapidly but leave a rough surface.

The rate at which an article to be ground passes horizontally across the wheel or *vice versa* also affects the finish, a rapid traverse giving a better polish than a slow traverse.

**Rate of Wheel Wear.** The durability of an abrasive wheel, etc., usually depends on the grade or toughness of the binding agent, wheels with a coarse grit and soft grade wearing away comparatively rapidly. The total amount of work done by a wheel or other abrasive appliance

is increased by using a finer grit or a harder grade.

The durability of a grinding-wheel varies according to the conditions under which it is used. When conditions are almost ideal, a wheel may remove 20 cu. in. of steel for 1 cu. in. of wear from the wheel. With careless or ignorant use, however, not more than 2 cu. in. of steel may be removed per 1 cu. in. of wheel worn away. In grinding very large chilled-iron rolls 16 cu. in. of chilled iron may be removed for each 1 cu. in. of wheel worn away.

*Lack of durability* may be attributed to—

1. Wheel not in balance.
2. Wheel too soft for the work.
3. Work speed too fast for the wheel grade.
4. Rest or support insufficiently steady.
5. Wheel spindle too loose in the bearing.
6. Very careless and irregular hand feeding.
7. Any vibration of the machine or work.
8. Improper lubrication of the work.

*To increase the durability* of a wheel—

1. Use an automatic feed.
2. Support the work rigidly with plenty of steady rests (no springs).
3. See that the wheel is well balanced.
4. See that there are no heavy lacings or knots in the belts which drive the work and the wheel.
5. Remove causes of vibration.

**Composition of Abrasive.** The chemical nature of abrasive wheels, etc., is often more important than is commonly supposed. Thus, for grinding materials of a high tensile strength—such as all steels and the harder bronzes—an aluminous abrasive should be used. If, on the other hand, the material to be ground is of low tensile strength—

such as cast iron, chilled iron, brass, soft bronzes, aluminium, copper, granite, marble, leather, and wood, then carbide abrasives are preferable.

To get the fastest work from a wheel, and also the longest life, the work should pass before it through a distance greater than half the width of the wheel and less than the full width of the wheel during each revolution of the work. It is also advisable to take the cuts very quickly across the work, not only to secure a large output but also to obtain the greatest efficiency from the wheel.

In comparing abrasive appliances made by different manufacturers or of different materials, it is most difficult to ensure reliable results. The letters and numbers used by the manufacturers do not coincide and no simple means of comparison (other than actual test) exists. Thus, a 20 grit carborundum wheel of 6 grade, by the Carborundum Company, corresponds to an Alundum wheel of Q grade, and these wheels behave quite differently when applied to grey iron castings. Moreover, if the same abrasive be used with a vitrified and silicate bond respectively, the former will be more porous and free-cutting. To overcome these discrepancies a standard grading is desirable. F. B. Jacobs has made the excellent suggestion that the present letters used to indicate grades should be replaced by numbers and that all abrasive wheels, etc., should be tested as to their grade before being sent out. This suggestion appears to overcome all real objections to the present system of lettering. Various tables have been published to show the designations used by various manufacturers for certain grades. Unfortunately, these are often far from accurate and they are, therefore, liable to be misleading. So far as the author is aware, no fully reliable and impartial table of comparisons has yet been published.

**Grit of Abrasive.** The fineness or grit of an abrasive has an important influence on the purposes for which it may be used. Coarse grains are used for operations where the rapid removal of stock is necessary, while the finer sizes are used in wheels intended to remove a small amount of material and produce a good finish on the work.

The flours are used in very fine oilstones, rubbing bricks, etc.

When an abrasive article is made of " straight grit " it is understood that all the particles are of approximately the same size. When a " combination " or " mixed grit " is used, particles of various sizes, and possibly of several materials, will be included. When the abrasive particles are suitably selected a mixed grit is sometimes preferable, as the abrasive will cut rapidly at first and, as the coarser particles are worn down, the finer ones will impart a fine finish on the work.

**Selection of Bond.** The binding agent or bond has an important influence on the suitability of an abrasive wheel, etc., for various purposes. The proportion of bond is also important. If too much bond be present, the abrasive articles tend to " glaze " badly owing to the bond not falling away with sufficient rapidity from the cutting point. With too little bond, on the contrary, the articles are weak and, in the case of wheels, cylinders or rotating rings, they may be dangerous on account of their liability to break when in use.

(i) *Rubber-bonded* abrasives are very tough and resistant and so are specially suitable where a bond of exceptional strength is required in conjunction with a thin wheel or ring. This is the case in various cutting operations, such as slotting iron plates, sawing stone, cutting glass and saw-teeth or sharpening milling cutters of awkward shape, as well as in cutting metals, grinding chilled iron rolls, and in other work where a fine finish is required. Rubber-bonded wheels are also used where it is necessary that the shape of the abrasive article should be retained as long as possible. This is particularly the case with the thin cutting discs used by watchmakers, dentists, etc.

(ii) *Shellac-bonded* wheels are used for cutter and

reamer grinding, pointing drills, sharpening knives, saws, and other edge tools. They are also used for the same sorts of work as rubber-bonded wheels but, as they are more elastic, they can be used to give a finer finish. They will not stand high temperatures, but can be used for wet or dry grinding. They are less porous and less free-cutting than wheels with a vitrified bond. They are singularly free from "glazing," as the baked shellac has not the stickiness characteristic of the natural material.

(iii) *Silicate wheels* are very close in texture and, as they cut freely, they are very useful for grinding tools and cutlery.

(iv) *Vitrified Bond.* Abrasive articles made with a vitrified bond are characterized by a high porosity, a great resistance to heat and acids and great freedom in cutting. They may be used for almost any purpose if care is taken to select them of suitable grit and grade, but when very thin cutting wheels are required it is often preferable to use a shellac or rubber-bond.

**Wet Grinding.** The water used in making abrasive articles is employed for producing a plastic mass suitable for moulding. If it is clean and not brackish, its impurities are usually of small moment. When water is used during the grinding process its function is to carry away the heat resulting from the friction between the abrasive and the article being ground and to wash away any loose particles dislodged by the grinding.

For many purposes solutions of soap or emulsions of oil and water are preferable to plain water. A solution containing 2 oz. of carbonate of soda per gallon of water has the advantage of not producing rust, especially if a little lard oil is mixed with it. Also, the carbonate of soda prevents the surface of the wheel from getting greasy, and keeps it in a clean cutting state.

Grindstones are softer when wet than dry and

should not be left partly immersed in water or they will wear unevenly. Stones made with sorel cement as a bond should not be used for wet grinding as the cement is disintegrated by water.

**Hardness of Abrasive.** The grade or hardness of the abrasive itself largely controls the purposes for which it may be used. The hardness is usually expressed in terms of Mohs' scale in which certain substances are arranged in a definite order of ascending scale of hardness as follows—

1. Talc.
2. Rocksalt or gypsum.
3. Calcite.
4. Fluorspar.
5. Apatite.
6. Felspar.
7. Quartz.
8. Topaz.
9. Corundum or sapphire.
10. Diamond.

It is important to observe that these numbers have no numerical relation to each other. Thus, topaz (8) is not twice as hard as fluorspar (4), or four times as hard as gypsum (2). Even when used with due regard to its limitations, Mohs' scale is misleading as there are not equal differences in hardness between consecutive numbers of the scale. Thus, there is a much greater difference in hardness between diamond and corundum than between corundum and topaz. Nevertheless, Mohs' scale is in common use, principally because materials harder than corundum present great difficulty in being properly tested for hardness. Artificial aluminous abrasives are considerably harder than corundum, though not nearly so hard as diamond, and silicon carbide abrasives are between the diamond and the artificial aluminous abrasives in hardness.

**Grade of Wheels, etc.** The hardness or grade of a grinding-wheel, etc., must be distinguished from the hardness of the abrasive particles. The term "grade" relates to the behaviour of the wheel as a whole and particularly as regards the tenacity with which the abrasive particles are retained in position when the wheel is in use. A maker of abrasive wheels does not consider the hardness of the abrasive nor the depth nor rate of cutting when speaking of a "hard" wheel: he refers solely to the binding power of the bond. Consequently, the grade of the wheel depends on the nature and percentage of bonding agent used. A vitrified bond is the hardest binding agent, a silicate bond is next and rubber and shellac bonds are relatively soft. The larger the proportion of bond the harder the wheel. The softest wheel now used is H; the hardest now used is T. Wheels of grade H are seldom used, and wheels as hard as P, Q, R, S, and T should not be used for grinding rough forgings, as such work disintegrates the wheel rapidly. Where wheels are used for grinding the burr left by welding, or for grinding sharp fins from castings, they should be of very hard grade, such as S, T, and U. For most purposes, O is the hardest grade of wheel which can be used to advantage.

It must be observed, however, that the hardness or grade of an abrasive wheel or cylinder appears to vary with the speed at which it rotates. Thus, a soft wheel used above its normal speed appears to be harder than it is, and on reducing the speed of a hard wheel it appears to become softer. Hence, by varying the speed within reasonable limits a wheel which is normally too soft or too hard, may be used satisfactorily. As a wheel wears,

its peripheral speed is reduced and the wheel appears to soften, but on increasing the number of revolutions per minute, so that the original peripheral speed is obtained, the wheel appears to regain its former hardness.

Many workers suppose that the faster the work revolves and the harder the wheel employed, the greater will be the output. Under such conditions maximum driving power is absorbed and maximum wear is caused in the machine, but in most cases the work produced is inferior to that which could be produced more quickly and with less effort by the use of softer wheels and lower work speeds.

The *toughness* of abrasive articles is, like the hardness, dependent on the bond. This property is a special characteristic of articles with shellac or rubber bonds, but those with silicate or vitrified bonds can also be made moderately tough.

Toughness is very desirable because—whilst the individual cuts of each abrasive particle are small—they are deep enough to put great pressure on the grain, which, to be efficient, particularly in cutting materials of high tensile strength, must possess the property of toughness in order to resist that pressure. Silicon carbide abrasives are extremely hard, but are not so tough as the aluminous abrasives.

One peculiar relationship between hardness of the work and grade of the wheel may be mentioned. When an experienced grinder changes from soft to hardened steel, he puts on a wheel of softer grade, although he may continue using the same kind of abrasive. There are two reasons why this should be done—

1. The harder steel will dull or glaze an abrasive more rapidly than will the softer steel ; so a softer

grade of wheel is employed which does not hold the worn grains as long.

2. The harder steel, being somewhat brittle, is not as tough as the softer steel and has less tendency to tear out the worn abrasive grains.

**Hardness of Work.** The hardness of the work being ground determines also to a certain extent the temper as well as grain-size of the abrasive best suited to that work. Hence, different abrasives and wheels of different grades must be used for different kinds of work.

**Peripheral Speed of Wheels.** The speed of rotation of abrasive wheels, cylinders, and the like should be adjusted according to the work on which they are engaged. If a wheel is rotated

TABLE II

PERIPHERAL SPEEDS FOR GRINDING-WHEELS IN VARIOUS APPLICATIONS

| Application. | Peripheral speed of wheel. |
|---|---|
| | *Ft. per min.* |
| Cylindrical grinding | 5,500 to 6,500 |
| Snagging and general off-hand grinding on bench and floor stands | 5,000 to 6,000 |
| Surface grinding | 4,000 to 5,000 |
| Knife grinding | 2,000 to 3,000 |
| Hemming cylinders | 2,100 to 2,400 |
| Tool grinding | 4,000 to 5,000* |
| Vertical surface grinding machines | 4,000 to 4,500 |
| Elastic and rubber cut-off wheels | 9,000 to 12,000 |
| Polishing wheels | about 7,000 |

* Some large users of grinding-wheels regard as maximum peripheral speeds for machinist's tools 800–1,000 ft. per min., and for carpenter's tools 550–600 ft. per min.

below its normal speed it will behave as though it were of lower grade and soft, whilst a wheel driven at an excessive speed will appear to be hard and too abrasive.

The speeds specified in Table II are typical, but should be modified to suit particular cases.

Except under expert advice the maximum peripheral speed at which grinding-wheels rotate should not exceed 3,400 ft. per min. This corresponds to the speeds of rotation shown in Table III for wheels of various diameters.

TABLE III

REVOLUTIONS PER MINUTE CORRESPONDING TO A PERIPHERAL SPEED OF 3,400 FT. PER MIN.

| *Diameter of wheel.* | | *Rev. per min.* |
|---|---|---|
| *ft.* | *in.* | |
| 8 | – | 135 |
| 7 | 6 | 144 |
| 7 | – | 154 |
| 6 | 6 | 166 |
| 6 | – | 180 |
| 5 | 6 | 196 |
| 5 | – | 216 |
| 4 | 6 | 240 |
| 4 | – | 270 |
| 3 | 6 | 308 |
| 3 | – | 360 |
| 2 | 6 | 433 |
| 2 | – | 541 |
| 1 | 6 | 721 |
| 1 | – | 1,082 |
| – | 6 | 2,164 |

For speeds higher than 3,400 ft. per min., slightly softer grades should be used to offset the harder

cutting action ; for lower speeds it is better to use slightly harder grades than would ordinarily be supplied.

For polishing purposes a much higher speed is desirable ; thus, the cloth wheels known as " mops " or " dollys " used for buffing metals usually run at from 4,000 to 5,000 r.p.m. for a wheel 12 in. diameter.

Messrs. Alfred Herbert, Ltd., Coventry, publish on behalf of the Norton Company a handy sliding scale which enables the speed, diameter, etc., to be ascertained without making troublesome calculations.

**Surface Speed of Work.** It is impossible to state exactly the speed at which any work should be ground. This is largely a matter of experiment, as the speed should be suited to the abrasive and to the nature of the material to be ground. On Norton cylindrical grinders a peripheral speed (for the work) of from 60 to 80 ft. per min. is often used for roughing, and from 30 to 40 ft. per min. for finishing. It is customary to use a higher surface speed of work for rough grinding than for finishing (*see also* p. 89).

In grinding cylinders, the speed of rotation of the article to be ground is often of great importance, as by running the grinding-wheels at constant speed and varying the speed of rotation of the article to be ground, it is easy to secure uniform results from wheels having a variation in speed of 2,000 ft. per min., and a variation from true grade within practical wheel-making limits. Thus, by varying the speed of the article to be ground, the necessity for variable revolutions for the wheel, or close limits of speed and grade for the wheel, are made unnecessary. Variable speed for the work accomplishes all that variable wheel spindles can accomplish and much more, in a more simple way and at less expense.

**Area of Grinding Contact.** The shape and size

of an abrasive article and of the portions of the article to be removed by grinding require consideration. For instance, if there is a large area of contact between the abrasive and the material to be ground, a relative soft wheel or other abrasive appliance should be used. When there is only a small area of contact an abrasive wheel, etc., of harder grade should be employed. This is especially true in snagging and off-hand grinding. In cylindrical grinding the contact varies with the diameter of the wheel and the work, increasing with larger work or with a larger wheel and thus making a softer grade of wheel desirable.

**Type and Condition of Grinding Machine.** Light, flimsy machines and those improperly secured to the foundation require the use of harder grades of wheels than would ordinarily be used. This is to counteract the tendency of the face of the wheel to be pounded away by vibration in service. For the same reason, if the spindle of the machine is loose and cannot be put in good condition, a harder grade of wheel must be used than would otherwise be recommended.

The following precautions are essential—

1. The wheel must be fixed properly in a spindle which is held firmly in rigid bearings having no play. Should there be any play in the spindle bearings, even a few thousandths of an inch, it will seriously handicap the work and result in a bad and inaccurate finish. There must be no vibration in the wheel-head, or "chatter" will result.
2. The wheel must rotate at the correct speed.
3. The machine should be perfectly rigid, free from all vibrations and casting strains, and the slides should be perfectly flat and true.
4. The work holder should be exceptionally stiff and

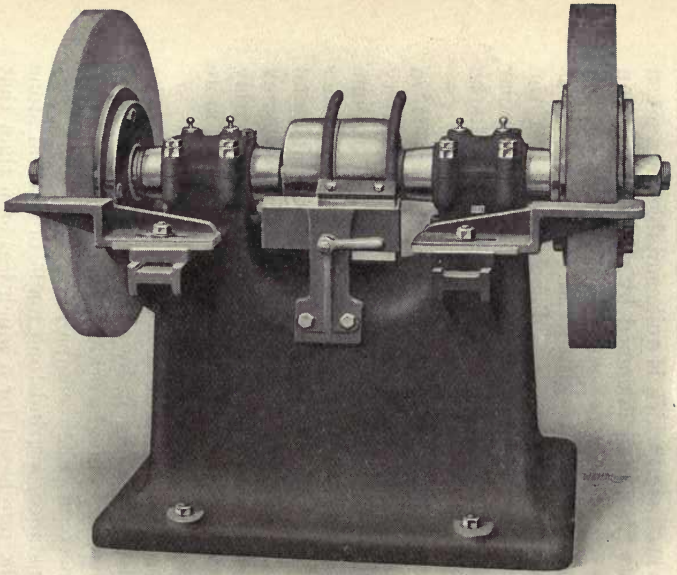
rigid, and if the work moves it should rotate and/or traverse at the correct speeds.

5. The work should be fed on to the wheel, or the wheel on to the work, at a correct rate or depth of cut.

**Personal Factor.** The personal factor is of great importance in the selection of an abrasive article, as a wheel, etc., which is quite suitable for a given purpose may be condemned by an unskilled man or by one who is not sufficiently well instructed in the particular work in hand. So important is the personal factor that different men on the same kind of work and using precisely similar machines, may obtain quite different results as regards durability or finish.

A common mistake made by grinders is in expecting one grade of wheel to do a great variety of work. A wheel admirably adapted for one class of work will prove quite inefficient for another class, so that it is advisable to keep at hand wheels of several grades. The greater economy effected will more than recoup the extra outlay involved, and the work done will be far more satisfactory.

**Overall Cost.** The total cost of removing a worn abrasive, replacing it by a new one and getting the latter into good working order should be taken into account when comparing various abrasives. For instance, a grindstone made of natural stone may be purchased for a much less sum than that asked for one made of an abrasive with a bonding agent, but if the additional costs mentioned above are taken into consideration, the artificially-made wheel will eventually be found to be much cheaper as well as more durable.



(*Mitchell's Emery Wheel Co.*)

FIG. 6.—DOUBLE DRY GRINDER FOR BENCH-MOUNTING.

## ABRASIVES FOR SPECIFIC APPLICATIONS

Although it is not possible to specify in detail the nature and properties of an abrasive appliance for any given purpose, unless the whole of the conditions—some of which are purely local—are known, the information in the following paragraphs should enable a user to confine his choice within conveniently narrow limits.

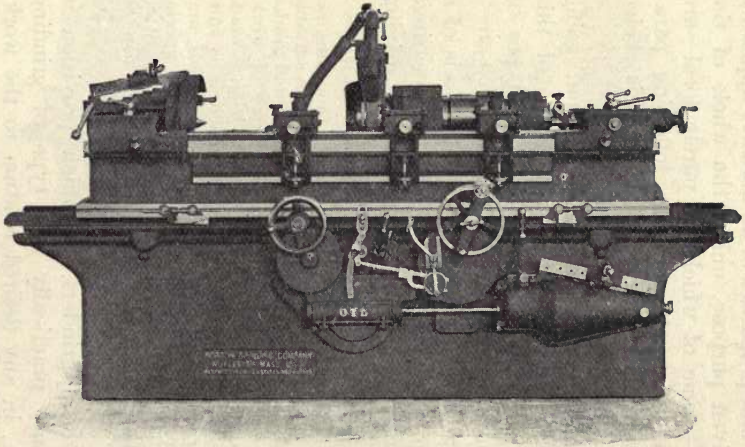
**Types of Grinding Machines.** Without going into details which lie beyond the scope of this book,* it may be said that the three types of grinding machines most commonly employed are—

(1) A pair of wheels mounted on the ends of a short shaft which is carried by two bearings between which are the fast and loose driving pulleys.

This machine may be arranged for bench-mounting (as in Fig. 6) or it may be carried from the floor on a suitable pedestal. The wheels may be of different grits and grades or of different shapes to suit various classes of work. Simple work rests are provided, but no provision is made for graduated or mechanical feed. The machine is suitable for sharpening tools, for removing excrescences, and for smoothing the surface of work on which no special precision is required. Safety guards should be fitted to the wheels (*see* Chapter IX). The machine can be arranged for wet grinding.

(2) Universal grinders, in which provision is made to use practically any type of grinding wheel, etc., in any desired relation to the work, both as regards setting and relative motion.

* For further information on the principles, equipment, and methods of precision grinding, the reader may refer to *Grinding Machines and Their Use*, by Thos. R. Shaw, uniform with this volume (Pitman, 2s. 6d. net).




(*Alfred Herbert, Ltd., Coventry.*)

FIG. 7.—NORTON PLAIN GRINDER.
16 in. by 50 in.

These machines are capable of performing external or internal grinding (parallel or taper), surfacing, and tool sharpening, etc., but increase in specialization is responsible for much work being taken away from universal grinders and being put on other machines which deal with one kind of work only. This results in increased accuracy and a great economy of time. It is curious to note that so great is the present specialization in grinding machines that the firms who build the leading machines confine their labours to a few types alone. Hence, there are a few names associated chiefly with universal cylindrical grinders, a few others with the hole and face-grinders, some with the disc design, a good many with cutter grinders, and so on.

(3) Plain grinding machines, which are built specifically for plain cylindrical grinding and deal more quickly and efficiently with this than do universal grinders. The modern plain grinder is built very strongly for heavy work, high production, and great accuracy. A typical machine is illustrated in Fig. 7.

(4) Internal grinders, in which a grinding-wheel is carried at the end of an overhung shaft so that it can operate on the internal surface of cylinders, etc.

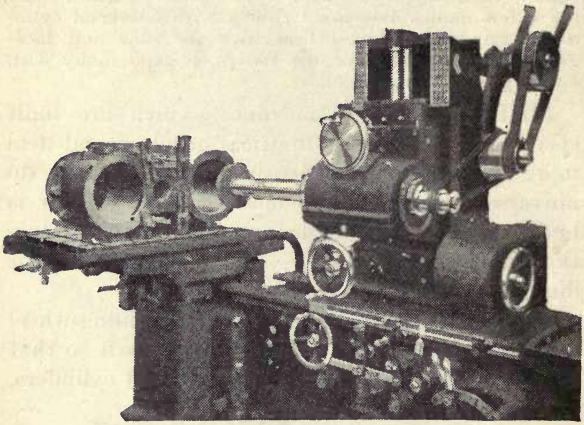
The work may be rotated by a chuck, the grinding-wheel spindle being carried on a slide-rest, which can be moved across the bed as required. A greater variety of work, however, can be done by a machine, such as that shown in Fig. 8, in which the grinding-wheel spindle has a planetary motion and the work is held on a table which is set conveniently at the commencement of the operation, and thereafter remains stationary.

(5) Plane surface grinders, which often replace with advantage the functions of a milling or planing machine.

Four main types of these grinders are made in which the work is either rotated or moved to and fro beneath the periphery of a disc-wheel or beneath the annular face

of a cup-wheel. According to circumstances the work may be bolted to the supporting table or held by magnetic chucks.

**Cylindrical Grinding.** Grinding is invading the province of the lathe more than that of any other machine tool and is, indeed, rapidly replacing the practice of fine turning. The reason for this is



*(Chas. Churchill & Co., Ltd.)*

FIG. 8.—CYLINDER GRINDER; PLANETARY SPINDLE TYPE.

that grinding renders practicable higher refinements in dimensions and in approximations to a truly circular shape. Also, it renders unnecessary any higher accuracy in turning than that of leaving enough material for finishing by grinding. By this means a skilled turner can be replaced by a comparatively unskilled hand, and in many cases forgings may be stamped and then ground without any preliminary turning at all. Thus, in modern

manufacture, multiple-throw crank-shafts and cam-shafts of automobiles, and of Diesel and other internal combustion engines are now commonly ground without any preliminary rough turning, but for pistons, piston-rings, and (in some shops) cylinders, a rough cut in the lathe precedes the grinding.

*External Cylindrical Grinding.* In its simplest form the external grinding of cylindrical surfaces is quite easy, but in some of the more complex forms of cylindrical grinding several years' experience are essential. Moreover, there are several matters in connection with cylindrical grinding about which there is still much difference of opinion.

In external cylindrical grinding the article to be ground revolves on a lathe and either the article is carried past the wheel or the wheel is carried past the article by a traversing device. Both arrangements give satisfactory results in ordinary work, but in special cases the stationary wheel-mount appears to be best. The wheel is made to approach or recede from the work by a screw motion termed a cross-feed, and by this means light or heavy grinding is effected. The respective speeds of the wheel and work have a great influence on the result, and whilst no hard and fast rules can be given, it will usually be found that the peripheral speed of the grinding-wheel should be constant, that of the work being varied as required.

The following *peripheral speeds* for the article to be ground are recognized as standards, but they

are only approximate and should be modified to suit each individual case—

| | *ft. per min.* |
|---|---|
| Cast iron | 40 |
| Cast iron—finishing | 50 |
| Steel—rough grinding | 25 |
| Steel—finishing | 35 |

When good results cannot be secured and it is thought that the wheel is at fault, a remedy may often be found in changing the speed of the work.

In "*roughing out*" *steel* the traverse or horizontal distance through which the work travels past the wheel or *vice versa* should be almost equal to the width of the grinding-wheel for each revolution of the work. Thus, if a wheel with a 3-in. face is used, the traverse should be 2⅞ in. For *rough grinding cast iron* a small traverse and a deep cut are preferable. For *finishing steel* the traverse should be reduced and the speed of the work increased. For *finishing cast iron* there should be as few passes as possible.

For grinding *crankshafts* the work is fed directly to the wheel by means of a cross-feed, the wheel having no traverse motion. Alumina or carbide wheels of moderate hardness are used, generally with combination grits of 16–24. Care must be taken that the corners or edges of the wheels do not wear away too rapidly. For finishing crankshafts, softer wheels of 36–40 grit are employed.

For *calendar rolls* and the rolls used in flour mills, shellac-bonded wheels of medium to soft grade and 24–80 grit are usually employed, as they are required to impart a fine finish. These wheels should have a peripheral speed of 5,000 ft. per min., the rolls having a peripheral speed of from 15 to 60 ft. per min., according to local conditions.

For grinding *rolling-mill rolls*, as used in the manufacture of steel sheets and plates, soft wheels should be employed on account of the large area of contact. The peripheral speed of the grinding-wheel should be about 5,000 ft. per min., and that of the roll about 150 ft. per min. The grit and grade are the same as for calendar rolls.

For small pieces, the quickest method of grinding is to hold the work on a circular magnetic chuck, or if it is

beyond the capacity of a circular chuck a machine with a reversing table must be used.

*Internal Cylindrical Grinding.* For internal grinding quite small wheels are used and they rotate in the interior of a cylinder or other article to be ground. In addition to its rotation about its own axis, the wheel rotates in a circle by means of a planetary motion. When possible, the grinding-wheel should revolve in a direction away from the operator and the cylinder in the opposite direction, i.e. towards the operator. For internal grinding, cast iron and bronze are usually ground dry, but steel is ground wet, though in many cases it may be ground dry with satisfactory results.

The wheels have a peripheral speed of from 4,000 to 6,000 ft. per min., whilst that of the work is from 25 to 100 ft. per min. The grades of the wheels should be the same as for external cylindrical grinding, but the work should be driven at a slower speed to give the freer cutting necessary for the increased surface contact.

Carbide abrasives are generally used for grinding cast iron and bronze, and aluminous abrasives for steel. Wheels of medium grade are used with a grit of 36–50 for most work, but for special cases wide departures are permissible. The wheels used for internal grinding must be kept as true as possible, and for this purpose a carbide block rather harder than the wheel is often as effective as a diamond and much cheaper.

For internal grinding it is found advisable to rough out by the dry process, and then to obtain a more accurate finish by applying a coolant. Dry grinding is a quicker operation, and while this is being carried out internally, much of the heat may be dissipated by the external application of water.

**Surface Grinding.** For grinding surfaces truly

parallel and for obtaining a good finish wheels, etc., of medium-soft grade should be used. The grit—which depends on the finish desired—varies from 36 to 80 mesh for ordinary work, but for highly accurate fitting 240 grit may be employed. For grinding steel articles aluminous abrasives —particularly corundum—are chiefly employed, but carbide abrasives are also used extensively.

The articles or parts to be ground may be fixed to a moving bench or holder by clamps, but when they are small or awkward in shape a magnetic chuck should be used.

In vertical grinding machines special care is needed in selecting suitable wheels, as a slight change in the hardness may spoil the work. The manufacturers of such machines will usually advise as to the best wheels to use.

For grinding *castings and forgings* it is false economy to use wheels less than 20 in. in diameter, wheels 30 in. by 4 in. being the most suitable, though little used. Castings are sometimes cleaned by exposing them to a blast of sharp sand and air, known as a *sand blast.*

For grinding *file blanks and axes and for surfacing ploughs,* natural grindstones are preferred to artificial ones, chiefly on account of their much lower cost, but partly because no artificial wheels on the market produce exactly the surface required. In the near future, however, artificial grinding-wheels will probably be used for this work.

*Steel dies and punches* are best ground with an aluminous abrasive of soft or medium grade, 36 grit and a peripheral speed of 5,000 ft. per min. The grinding may be either wet or dry, but wet grinding is preferable for large dies.

For grinding *cams,* prior to hardening, aluminous or carbide abrasives of P–V grade and 16–24 grit are employed. For rough grinding hardened cams similar wheels, but of grade H–K and grits 24–40

are used, whilst for finishing the grinding the wheels should usually be of G–J grade and 36–50 grit.

In grinding *balls* for ball bearings, the rough grinding is usually effected by rotating the balls in contact with an emery wheel. Many different types of machine are in operation to effect this, and employ ingenious devices to hold the balls. Finish-grinding is effected in two stages, the first with fine dry emery, and the final stage with a mixture of emery and oil. Much depends upon this final operation, which requires frequent gauging to ensure accuracy. The dull finish is improved by burnishing in a tumbling barrel. For highly finished work a finer grit is used. The abrasive should be trued with a diamond as soon as it shows signs of "glazing."

**Sharpening Edge Tools.** In sharpening *milling cutters and edge tools*, the tool should be traversed rapidly past the grinding-wheel and, at the same time, applied to it with a light pressure. For large cutters, a cup-shaped grinding-wheel is often preferred to the more usual disc. Owing to the great variety of cutters and edge tools it is not possible to specify the best type of wheel with great accuracy, but, broadly, for tools made of high-speed steel the wheels should be of 4–15 (or M–P) grade and 36–46 grit, whilst for tools made of carbon steel they should be of similar grade but rather finer (50–60 grit), shellac-bonded wheels or cups being preferred.

Straight wheels should revolve at 3,000 to 4,000 peripheral ft. per min., though wheels of 40 to 50

grit may revolve rather faster. Cup wheels should revolve at 2,500–3,500 ft. per min.

High speed steel edge tools should be ground dry ; those of other steel should be ground wet.

When *blocks* or *hones* are used for grinding fine edge tools the stone must cut freely so as not to heat the work and spoil the temper, and yet it must be soft enough to wear away with sufficient rapidity to keep the abrasive particles sharp. At the same time, a stone slab or wheel which has no free grit is of no use for sharpening tools, and when examined under a microscope even the finest Turkey oil-stones will be found to contain relatively large particles of abrasive in a mass of exceedingly fine grained material. For hones, blocks, and stones and for sharpening steel tools corundum is an excellent abrasive.

In *sharpening saws* there are two distinct operations—roughing and pointing—the former being a very drastic operation which requires very skilfully selected grinding-wheels or the temper of the saw will be spoiled. The wheels should be made of an aluminous or carbide abrasive and sufficiently soft to cut freely but not to wear away too rapidly. They are usually of H–P grade and 30–50 grit, combination wheels being very useful for this class of work. The bond may be either vitrified or shellac. The wheels may revolve at a surface speed of 3,500 to 5,500 ft. per min. Grinding-wheels used for sharpening saws may be straight or curved ; the former sometimes have the edge bevelled to the same angle as the saw tooth.

**Dental Grinding.** The introduction of carbide

abrasives into dental work has added greatly to the comfort of patients and enables the dentist to do his work more rapidly, with a better finish and with less destruction of tissue. Specially shaped " points " are used for this work.

**Pottery Grinding.** For grinding off superfluous material in pottery and other clay products, abrasive wheels are particularly suitable, as the work can be done rapidly and with great accuracy. The wheels must be selected according to the hardness of the body or glaze to be removed, those with a medium or fine grit and a medium grade being preferable.

**Cutting-off Wheels.** Thin wheels made of carbide or aluminous abrasives are very useful for cutting off portions of metal or for cutting bars, etc., to a given length. They should have a shellac or rubber bond and a surface speed of 7,000 to 8,000 ft. per min.

**Polishing Metals.** For polishing metals loose powders are employed. Such powders may be used in the dry or wet state, and may be rubbed on to the material to be polished or they may be applied by means of a wheel (or " dolly ") composed of discs of cloth.

For polishing *steel* articles, blocks of carbide or aluminous abrasive or cloths or papers covered with emery or corundum are largely employed. For polishing *brass and other softer metals*, very fine silica, quartz flour, emery, carbide or aluminous abrasives, crocus, rouge or whiting are employed. For *silver and gold* ware, slaked lime is largely used. The polishing powder is sometimes

tinted with rouge to disguise its nature, and to give white metals a slightly ruddy tint which improves their appearance.

In the so-called liquid polishes (Chapter VI) a little oxalic acid or other chemical detergent is sometimes added to the abrasive powder.

**Grinding and Polishing Non-metallic Substances.** For grinding and polishing *marble*, *stones*, and *glass*, crushed steel has proved very satisfactory on account of its hardness, sharpness, and toughness. It is, however, but little used in this country; sand, carbide or aluminous abrasives being generally employed. For final polishing, loose powders are used as in the case of metals (*q.v.*).

For producing a *rough surface on glass*, sand is largely used in what is known as the sand-blast process.

For *polishing glass* sand is largely used, but carbide abrasives are increasingly employed on account of their greater hardness and, consequently, more rapid work.

In polishing glass it is essential that the amorphous surface layer should be removed and that the forces applied to the glass should not be so great as to form conchoidal splinters. Therefore a softer tool of pitch, wax, hard felt, or paper, is employed with an abrasive medium of an extremely fine character that will form spongy accretions, the best being ferric oxide (rouge). By means of the abrasive, the prominences are reduced until the bottoms of the cavities are reached. After this, the polishing must be continued with the

removal of more glass, so that the final polish is effected with water.

Glass can also be polished with very fine carborundum which has been specially treated with hydrofluoric acid—using oil as a medium. Excellent results can also be obtained from the use of carbon and many other substances, provided they can be brought into the required physical condition.

For *cutting stone, marble*, and *glass*, a metal wheel with loose sand and water is largely employed, but grinding-wheels of carbide and aluminous abrasives of medium grade and 36–50 grit are being increasingly employed and are rapidly replacing metal wheels.

In surfacing, slotting, and moulding and other work on stone and marble, the use of carborundum wheels and blocks has greatly reduced the time required and has also increased the accuracy of the work.

In mitre-cutting, checkering, lacing, fluting, and beading glass, and for smoothing and bevelling the edges of lenses, wheels made of carbide abrasives are rapidly replacing metal wheels and natural stones, as the former work more rapidly and with greater accuracy, as well as being much more durable. Similar wheels are also used for cutting air vents in gas-globes, etc.

For *smoothing wood* and similar materials, garnet, emery, and sand, mounted on paper or cloth are largely employed, garnet being especially suitable for hard woods. For finishing wooden handles, sand mounted on endless belts is largely used.

In the *leather* industries, and especially in the

manufacture of boots and shoes, corundum and carborundum cloths are largely used for heel scouring and breasting and for buffing. "Compressed wheels" and carborundum drums about 18 in. in length and 16 in. diameter at the centre, tapering towards the ends, are largely used for finishing skins to be used in the manufacture of gloves and for suede leather.

For work in which an *exceptionally hard abrasive* is required, including the truing of abrasive wheels, diamond, bort or carbonado, is employed.

**New Methods in New Industries.** The growth of new industries which are not hampered by traditional methods of machining has had much influence on the advances in grinding practice. The principal factors have been the development of motor-car work and the remodelling of machine-tools. There is no portion of a motor-car of any type which is not now being tooled almost exclusively by grinding, though in the earlier days the work was done by turning, boring, planing, milling, etc.

New applications are constantly being made, and there are no signs of finality being approached. Grinding is evidently going to occupy a far wider sphere in the machine shop than it does even at present.

## CHAPTER VIII

### TESTING ABRASIVES AND POLISHES

DESCRIPTIONS of the accurate and detailed tests which are made by the foremost manufacturers

and users of abrasives are beyond the scope of this small volume, but mention may be made of various tests which can and should be made by every user of abrasives.

**General Observations on Service.** In the first place, a careful inspection of the wheels from day to day is a most important matter, particularly where high speeds are the rule, or there will be a risk of incurring disasters like those reported from time to time with wheels bursting, and so forth.

The volume of sparks produced when a grinding-wheel is in use gives a sure indication of its efficiency or otherwise, and of the conditions under which it is operating. If the sparks, or fragments of metal removed by the wheel are examined under the microscope, they should appear as veritable chips, resembling short cuttings or turnings (*see* Fig. 1, p. 7). If they are globular or globular shells (as in Fig. 2) they show that too much heat is being generated, so that fusion of the particles occurs.

If a wheel has been cutting properly, and then fails to do so—other things remaining unchanged —it is suffering from "glazing." The abrasive particles have lost their keenness and penetrative capacity, yet have not become detached from their matrix, which then sets up friction and generates heat. If a wheel which is being tried provisionally, becomes very hot and throws out few sparks, a wheel with a softer bond may be substituted with advantage, or the grit or materials of the wheel selected may be unsuitable. Frequently, more ample lubrication will solve the problem, or it

may be that an increase in the number of steadies is wanted. The effect of the latter is to prevent the work from running eccentrically. Eccentric running produces more sparks on the higher side, an evil, which if uncorrected, will be persistent. How slight an amount of eccentricity can cause trouble may be realized by the statement that sparks will be given off from a cylindrical piece of work when the depth of cut is only five-millionths of an inch.

**Quantitative Tests for Wheels.** The fairest test is to use the wheel under ordinary conditions for 50 hours or more, adhering strictly to the peripheral speed and other directions specified by the manufacturer and making careful notes of—

(i) The volume or weight of the wheel before and after use.*

The volume of a wheel in cubic inches is found by multiplying the square of the diameter by the width or thickness, then by 7,854 and dividing by 10,000, the measurements being in inches.

(ii) The weight of the material removed from the articles ground.

(iii) The time required to do this work.

(iv) The wages of the men employed in the grinding.

(v) The power required to do the work.

(vi) The number of articles ground, and their nature.

From these data may be calculated—

(*a*) The cost of abrasive per unit or per pound of material ground.

(*b*) The cost of labour per unit or per pound of material ground.

(*c*) The cost of power per unit or per pound of material ground.

The durability of a wheel is not a true test of

* In wet grinding the wheel should be dried before being re-weighed.

its value, for whilst a hard wheel will last longer than a soft one it works more slowly, involving a heavier charge for labour, and the cost of grinding the articles may, therefore, be higher than with a softer wheel.

Owing to the many factors involved, it is seldom possible to predict the actual cost of using any kind of abrasive from small scale or laboratory tests. For this reason, it is always best to rely on a test made on a full working scale, but under the best conditions possible. Small scale laboratory tests are, however, valuable in studying the effect of variations in the speed of the wheel or the work, and in making other adjustments with a view to increasing efficiency.

**Testing Grade and Grit.** The grade of an abrasive is tested as described on p. 41. The grit of an abrasive wheel or block is often difficult to determine. The best method consists in viewing it through a microscope, with a powerful light directed on the object, and measuring the size of the particles by means of an eye-piece micrometer. If several abrasive articles of known grit are similarly treated, it is easy to ascertain the grit of any other sample.

For coarse grits a pocket lens will serve instead of a microscope, if abrasives of known grit are available for comparison.

Notes on the testing of abrasive papers and cloths are given in Chapter V, p. 59.

A microscope is also invaluable for making comparisons of the effect of various abrasives on metals or other articles. To the naked eye many

different metals, or the surfaces of marble or other stones composed of kindred grains, appear to present an equal fineness; yet when they are suitably magnified vast contrasts can be seen among them. If specimens are examined under the microscope at intervals during the grinding, the process and effect of the abrasion may be followed to far better advantage than with the naked eye.

**Precision Grinding.** Abrasives, and particularly grinding-wheels, are largely used for the production of work in which accuracy of size is of such great importance that it is essential to take special precautions in working. The necessity for this will be clearly appreciated when it is realized that one chief object in using such wheels is to ensure well-fitting machine parts in instances where one ten-thousandth of an inch makes the difference between a tight and easy fit, while a few ten-thousandths represent a loose fit. The end operations in general engineering work, in which the highest accuracy is neither required nor economically possible, are quickened by the use of limit gauges with their standard allowances, but these workshop gauges in turn demand reference to standard gauges of a higher degree of precision. Such standard gauges for reference purposes are of an accuracy of 0·00005 inch, while flat gauges of the Johansson type are of an accuracy of 0·00001 inch, the errors being so small that they are still small when a number of the gauges are used in conjunction in testing a given piece. Modern grinding operations, carried out with

comparative ease with an accuracy of a few ten-thousandths of an inch, even with mass production and with a limited application of highly-skilled labour, provide a very marked advance in comparatively recent times in machinery operations, but such accuracy can only be obtained by the most careful attention to many details. Incidentally, the use of wheels running at high speeds also involves adequate protection for the workers, both as regards risk of direct personal damage and indirect ill-health due to dust.

**Judging Polishing Agents.** The quality of the polish depends on the smallness of the abrasive particles, their hardness, angularity or sharpness, and the ease with which they leave the polished surface. If the particles are too large they will leave unsightly, broad scratches ; if they are too hard the scratches will be thin, but very deep and difficult to eradicate ; whilst if the grains are too round they will roll about on the surface without producing any polish.

The best method of judging the efficiency of a polishing agent is by means of a microscope. A definite quantity of the agent (preferably in a suitable medium such as paraffin) is rubbed six times up and down a smooth, but dull piece of brass. The material is wiped off with a clean cloth and the surface of the brass is examined, first by the naked eye and afterwards under a microscope. The nature and number of the scratches gives a good idea of the suitability or otherwise of the polishing agent. If the scratches are too wide, a microscopical examination of the polishing agent

will probably show that its grains are too large. If an occasional large scratch among many small ones is seen, the microscopical examination of the polishing agent will probably show a small percentage of quartz or other hard rock. If the microscope shows that the grains of the polishing agent are sound and smooth, it is unlikely that the powder will be of much value for polishing, as its action will be very slow. Excessively sharp, angular pieces, on the contrary, usually scratch too much, and should be replaced by more globular particles with small facets on angular faces.

## CHAPTER IX

### ERECTION AND OPERATION OF MACHINES AND WHEELS

**Types of Machines.** The main features and functions of the principal types of grinding machines have already been indicated (*see* Chapter VII, p. 82), but it is here necessary to deal with certain constructional features which affect the quality of the work done. As good grinding machines are costly, it is inevitable that there should be concessions to the requirements of the smaller firms in the way of various attachments to make possible the performance of a variety of work on a single machine. The tendency, however, is towards the use of plain grinding machines or of special machines limited to one set of functions, every detail being considered and worked out for that puty alone.

Rotary abrasive appliances may be mounted in a fixed frame—in which case the article to be ground, cut or polished is moved gradually forward—or the work may be fixed and the abrasive mounted on a moving frame so that it travels both forward and from side to side. There is an increasing feeling that the latter principle is wrong, even in light machines; it is impracticable in heavy ones, where a wheel head may weigh between one and two tons. When a heavy wheel is expected to grind within $\frac{1}{4000}$ in., whilst revolving at a speed of 6,000 ft. per min. at the surface and operating across a cutting face from 2 to 4 in. wide, it is clearly not a good mechanical proceeding to traverse such a mass. The present practice, therefore, is to put plenty of mass into the wheel-head, and to support it rigidly directly from the floor. Then the only movement which it receives is that of feeding inwards to the work. Incidentally, also, the necessary travel of the table requires a long table, which, again, avoids excessive wear. A slow table or traverse speed should be used when taking heavy cuts, but a high traverse speed is preferable for finishing.*

**Constructional Features.** A machine which is too light or imperfectly made is always a nuisance and is liable to prove very expensive. It is only too easy for good work to be spoiled by such machines and they add unnecessarily to the cost of grinding, because they cannot be driven at the speed most appropriate for the work, and because

* *See also Grinding Machines and Their Use* by Thos. R. Shaw, uniform with this volume (Pitman, 2s. 6d. net).

of various "dodges" which must be used to obtain satisfactory results.

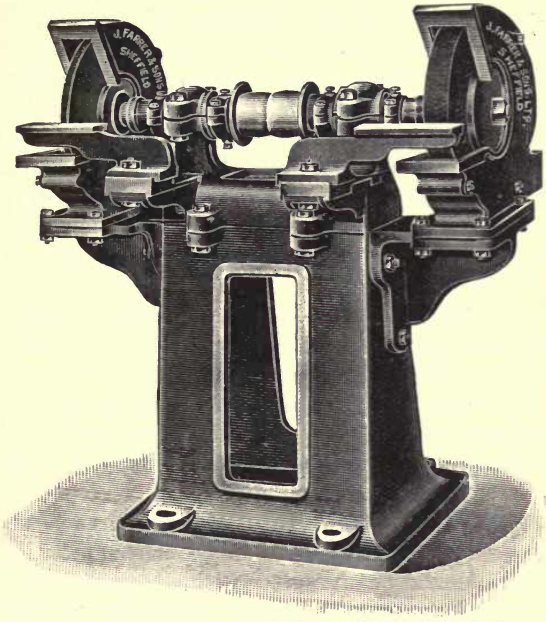
In the best machines no mild steel or cast iron is used for shafts and gears. High carbon or alloy steels alone are used for these. Nickel, nickel-chrome, or chrome-vanadium steels ensure strength and durability, without which the small shafts and gears of fine pitches would soon show serious wear. Friction is reduced by the universal fitting of ball-bearings for taking circular and end thrust. Lubrication is provided in various ways, ring-oiling to the main bearings, forced water supply to the work and the wheel, and a large supply-tank or tanks with a circulating pump. New forms of steadies have been evolved, and more are used, besides which steadies for some duties are specially designed. The necessity for supporting work almost continuously receives more recognition than it formerly did, and the work is better supported on the bottom and in opposition to the wheel.

The belt drives from cumbrous overhead shafts have disappeared from all except the smaller and medium-sized machines, as electric drives have largely displaced this clumsy method and permit overhead-travelling cranes, or overhead tracks to have free range. The large cylindrical grinding machines of to-day therefore have no belt drive from above. A motor is installed somewhere alongside the bed, and the grinding wheel is belt-driven from that; the work-speeds and the wheel-feeds are changed through gears enclosed in boxes protected from grit. The convenience of this arrangement, which is only rendered possible by the electric drive, is inducing manufacturers to adopt similar arrangements for the smaller machines.

**Guards.** It is not possible to provide an efficient guard for every kind of abrasive wheel, but wherever a guard can be used it should be provided. Some guards are unsuitable in design, others are too flimsy to withstand the shock of a bursting wheel, and others are capable of being so easily moved out of the way that they are seldom in active use. If workmen and employers only paid

sufficient attention to this matter many lamentable accidents would be prevented.

**Dust Collectors.** Artificial abrasives have in themselves no chemical effect upon the human



(*J. Farrer & Sons, Ltd., Sheffield.*)

FIG. 9.—TYPICAL PEDESTAL-TYPE GRINDING MACHINE WITH DUST COLLECTORS WHICH ACT ALSO AS SAFETY GUARDS.

system as the various human fluids have no action on the abrasive. But when men work in an atmosphere containing a large amount of abrasive dust the resultant irritation of the nose, throat, and

lungs produces conditions which may lead to tuberculosis or other diseases. For this reason and as a safeguard to the eyes, some form of protective hood and dust collector—preferably with a fan to carry off the dust in a current of air—should be used whenever dry grinding is done. Further, considerable quantities of abrasive dust are apt to collect on machine parts, especially those which are lubricated. Such bearing surfaces, and especially sliding surfaces, must be protected. The dust problem is entirely absent in wet grinding, in which an abundant flow of water or other liquid carries away the dust and also keeps the work cool, thus making possible a more accurate product. The workmen should wear goggles and respirators when a hood or dust collector cannot protect them fully from flying sparks. A convenient form of hood is shown in Fig. 9.

**Mounting.** A grinding wheel should be fixed carefully and securely between iron plates or washers about half the diameter of the wheel, with a sheet of thin rubber insertion, or one or two thicknesses of brown paper, on each side between the wheel and the washer-plates. It should never be mounted without washers, and the flanges should be of the same size; if one flange is larger than the other the wheel is stressed tranversely and may crack or "fly." Care should be taken in screwing up very thin wheels that too much force is not applied. No wheel of more than 12 in. diameter should be put on a spindle of 1 in. diameter and other sizes in proportion.

In order to prevent damage to the wheel through

defective mounting, the shaft or spindle sometimes has a cardboard packing between it and the wheel. This is not essential, but is advisable for very large wheels. In the case of wheels less than 36 in. diameter the metal bush should be just tight enough to enable the spindle to pass through it without hammering. If the spindle fits too tightly, the expansion of the metal used for the bush (as the wheel becomes hot) may crack the wheel. There should be sufficient space between the bush of the wheel and the wheel itself to accommodate the expansion of the wheel. Any screws should be tight enough to hold the wheel or cylinder in place but not so tight as to strain it.

Before being used, the wheels should be trued up on their own spindles with a truing tool, and they should also be turned up when they get out of truth through wear.

Grinding-wheels should revolve towards the rests, and the rests should be set close to the wheels so as to prevent work being jammed between the rest and the wheel. The rest must never be moved while the machine is in motion.

**Truing and Dressing Abrasive Wheels, etc.** A grinding-wheel consists of a very large number of single cutting points cemented or bonded together, and presented at very different angles. Their action is to produce a large number of very fine cuts simultaneously, the size of the cuts being determined by the size of the particles of the abrasives. As these cuts are exceedingly small (even much less than a thousandth of an inch),

accuracy can only be attained by the greatest precision in the shaping of the wheel on its axis. This is usually effected by "truing" or "dressing."

The terms "truing" and "dressing" are often confused. *Truing* usually denotes giving a grinding-wheel or other abrasive device an accurate shape or a surface which will enable it to produce a good finish to the work; whereas *dressing* usually denotes imparting a surface to a grinding wheel, etc., which will make it grind or cut more rapidly. Dressing frees the worn and useless grains and

(*Alfred Herbert, Ltd., Coventry.*

FIG. 10.—DIAMO-CARBO WHEEL DRESSER.

bond from the face of the wheel and presents new particles of abrasive.

To turn abrasive wheels, cylinders, etc., accurately to the required shape a diamond is necessary. Bort diamonds are sometimes used for this purpose, but carbonado or black diamonds—though more costly to purchase—last longer and are harder and more reliable. The diamond is mounted in a metal holder held in a suitable feeding device, as it is almost impossible to obtain the best results if the diamond-holder is held in the hand. Substitutes for diamonds are also used. The one shown in Fig. 10 consists of a steel tube filled with an intensely hard abrasive.

When wheels are used only for rough work or in order to give them a preliminary truing the ordinary wheel-dressers may be used (*see* Fig. 11). These consist of small wheels of irregular shape, made of specially hardened metal and mounted in a holder so that they rotate when in use. They are unsuitable for truing finishing wheels, but are excellent for wheels used for coarser work and are much cheaper than diamonds. In both truing and dressing, the tool should be held in a suitable holder, and it should be passed rapidly across the

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FIG. 11.—HUNTINGDON WHEEL DRESSER.

surface to be trued or dressed, with an even motion, only a light cut being taken at each traverse. In each case the wheel should be supplied with an abundance of lubricant, as in wet grinding.

**Vibration.** If either the article being ground or the grinding wheel vibrate to more than a negligible extent there will be "chatter marks" or faint lines which show on finished cylindrical work when it is lapped or rubbed in a tight fitting hole. Chatter marks caused by vibration in the work, the centres of its supports, or the table of the machine, appear in straight lines parallel to the axis of the work. Those caused by vibration of

the wheel, its bearings or the wheel-head, appear as spiral marks round the work. Occasionally chatter marks are due to the use of too hard a wheel; in this case they are wavy instead of straight or spiral lines.

*Vibrations in the work* are generally caused by: (1) bad centres in the work; possibly not the same angle as the centres of the machine; (ii) badly worn machine centres; (iii) machine centres not bedding properly in their sockets; (iv) work-head or tailstock not properly clamped on the table; (v) omission of properly fitted steady rests*; (vi) too fast a work speed; or (vii) a glazed wheel.

*Vibrations of the wheel* are generally caused by: (i) wheel loose on its sleeve; (ii) wheel out of balance; (iii) loose wheel spindle bearings; (iv) spindle itself not round; (v) grit under the wheel slide; or (vi) a clumsy fastening to the wheel spindle driving belt.

**Poor Cutting, Glazing, and Burning.** These defects are all due to the same cause, and to remedy them one or more of the following precautions should be taken. A softer or coarser wheel should be used; the pressure of the wheel on the work, or *vice versa*, should be increased; the area of contact should be reduced; the wheel should be "dressed"; or a lubricant with less oil (or no oil) should be used.

* Steady rests are just as much a part of the cylindrical grinding machine as the wheel itself, and those who do not use them on all fine work should not complain about the quality of the finish, although they may succeed in obtaining a satisfactory finish in some cases without their use.

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*Little Known Facts About Grinding*, by H. W. Dunbar. (Norton Co., Worcester, Mass.)

The under-mentioned Technical Primers, uniform with this volume (Pitman, 2s. 6d. net), deal with subjects of associated interest—

*Grinding Machines and Their Use*, by Thos. R. Shaw ; for details of precision grinding machines and practice.

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